GHOST RIVER AREA

BY

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ABSTRACT

Middle Cambrian rocks of the Ghost River area west of Calgary, Alberta are correlatives of the type Cathedral, Stephen, Eldon and Pika formations near Field, British Columbia. Sandstones and shales of the Lower Cathedral formation are thought to be lithologic equivalents of a transgressive diachronic Middle Cambrian unit in the subsurface and the Lower Cambrian St. Piran formation near Field. Younger carbonate units represent deposition in deeper water at a greater distance from the eastern shoreline.

The Ghost River formation is the western shoreline deposit of the transgressing Devonian sea and rests unconformably on Middle Cambrian strata. Younger Devonian, Mississippian, Pennsylvanian, Triassic and Upper Cretaceous units are similar to those described from other areas in western Alberta. Jurassic, Lower Cretaceous and lower Upper Cretaceous rocks are not exposed in the area.

Gently dipping Palaeozoic formations outcrop above the McConnell fault in a broad doubly-plunging syncline that is overridden on the west by the Costigan fault which underlies a westerly dipping homocline in Palaeozoic and Triassic rocks. Locally, erosion has removed much of the McConnell thrust sheet to expose the junction of the two faults. Formation of the Panther River thrust sheet below the McConnell fault folded the latter and formed the End Mountain syncline and an anticline to the west. The Costigan thrust and Ghost River tear faults resulted from the folding of this thrust sheet and are complexly related. West of the Costigan fault the Exshaw thrust is overlain by a homocline of Mississippian and younger beds.

Topography is controlled to a marked degree by structure and massive Middle Cambrian limestones which form steep-walled canyons in the eastern part of the area.

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INTRODUCTION

For over two hundred miles, the great McConnell thrust separates the Rocky Mountains and the Foothills belt in western Alberta. R.G. McConnell in 1887 first recognized the magnitude of this structure, and this thrust fault, later named in his honour, has been mapped for most of its length and has come to be regarded as one of the more important structures of the Rocky Mountains. The present investigation is a study of the structure and Cambrian stratigraphy of a previously unmapped area towards the southern end of this fault (Figure 1).

Ghost River map-area is fifty miles west-northwest of Calgary, Alberta and includes portions of Township 26, Range 9 W5 Meridian, Township 27, Ranges 9 and 10 W5 Meridian, and Township 28, Ranges 9 and 10 W5 Meridian. It is bounded on the north by the headwaters of Burnt Timber Creek, on the south by South Ghost River, on the east by the Rocky Mountain Front and on the west by the north-northwest valley of upper Ghost River.

Most of the map-area is occupied by Palaeozoic strata which form a pronounced salient above the McConnell thrust, and are expressed topographically as the Front Range of the Rocky Mountains. Upper Cretaceous sandstones and shales of the Foothills belt underlie these Palaeozoic rocks to the north, east and southeast of the McConnell fault (Figure 2).

Location and Accessibility

The Ghost River map-area is in the Rocky Mountain Front range north of the Bow River area (Clark, 1954)* and south of the

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* Refers to Bibliography on Page 115

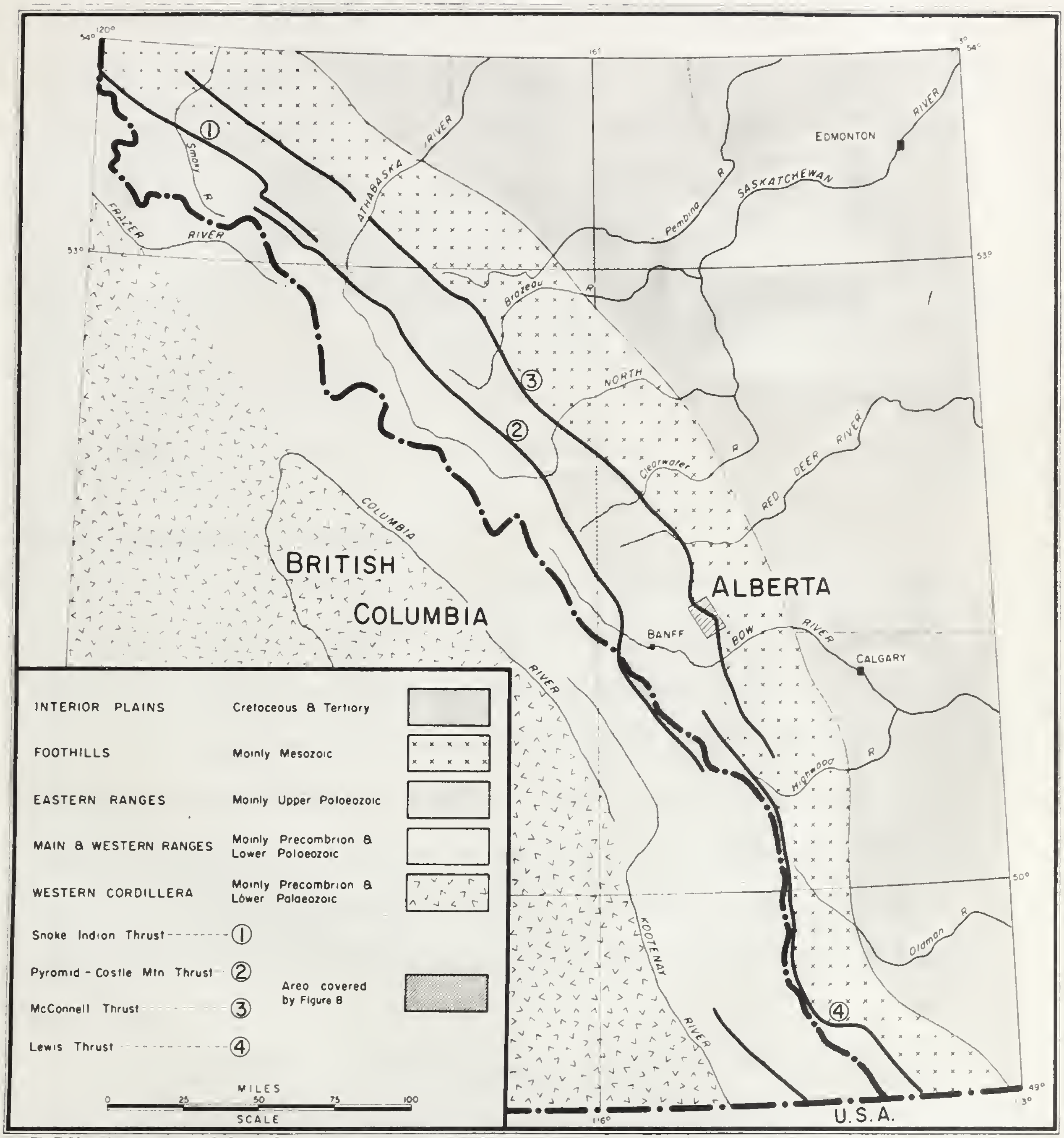

FIGURE 1

INDEX MAP SHOWING LOCATION
OF GHOST RIVER AREA

Panther River region (Hunt, 1956).

Most of the area is in the Bow Forest portion of the Rocky Mountains Forest Reserve. A small strip is in Banff National Park and surrounds Lake Minnewanka and Devils Gap. The map-area may be reached from Calgary via Alberta Highway IA, and the Forestry Trunk Road. The latter leaves this highway ten miles west of Cochrane and goes past the eastern boundary of the map-area, eventually reaching Nordegg in the Clearwater Forest. Forestry and seismic trails branching from the Trunk Road and entering the map-area from the east via the valleys of Burnt Timber and Waiparous Creeks and Ghost and South Ghost Rivers provide access to all the area mapped. The country surrounding Lake Minnewanka may also be reached by boat.

Previous Work in the Map-Area

The prominent valley occupied by Lake Minnewanka and Devils Gap was traversed by Dawson in 1885, (1886, pp. 141-143) who described Cambrian and Cretaceous beds but was unable to establish the relationship between the Mountain front and the Foothills. The following year, McConnell (1887, p. 33D), while constructing a structure-section across the Rocky Mountains, examined outcrops in Devils Gap and on South Ghost River. He first recognized the significance of the great Front Range thrust fault that now bears his name.

The Palaeozoic stratigraphy in Devils Gap and on Ghost River has been studied by Shimer (1913, p. 233), Allan (1915, 1916), Walcott (1923, pp. 463-464), Shimer (1926), Walcott (1928, pp. 259-263), deWit and McLaren (1950, pp. 55-61), and McLaren (1955, pp. 17-23).

Systematic mapping was not undertaken in this region before 1947, when Clark examined the Front Range south of South Ghost River. More recently the country north of the Ghost River area has been studied by Hunt (1956) and the area south of Lake Minnewanka by Miller (1957).

Present Work

Field mapping was carried on between August 25 and September 27, 1960. Foot traverses were undertaken with transportation from two base camps provided by Land Rover. Structural data were plotted directly on aerial photographs on a scale of 1" = 1500 feet and subsequently transferred to base maps on a scale of 1" = 4000 feet. In the western part of the map-area, formational contacts were traced from aerial photographs between relatively widely spaced traverses.

Lithologic samples were collected from all units below the Upper Devonian and were examined with the binocular microscope. The type Ghost River formation (see page 43) was closely sampled and fifteen thin sections and three insoluble residues were examined for textural detail. For microscopic descriptions, grain and crystal sizes are classified according to Folk (1959, p. 147) and colours are based on comparison with the Rock-Color Chart (Goddard, et al, 1951).

Fossils were collected from Cambrian, Devonian and Upper Cretaceous rocks in and near the map-area. These were identified by C.L. Balk (Cambrian) and P.S. Warren (Devonian).

Physiography

The Ghost River area straddles the boundary between the Rocky Mountain Front Ranges and the Foothills belt of west-central

Alberta. These physiographic subdivisions are underlain by folded and faulted Palaeozoic and Mesozoic rocks respectively. In the map-area the Front Range is a northerly extension of the Fairholme Range near Bow River. At the northern boundary of the area the mountains give way abruptly to typical Foothills terrane (Figure 2).

Bold limestone cliffs rising abruptly to elevations of more than 7000 feet from the forested foothills characterize the Rocky Mountain front throughout the area. Within the eastern Front Range, gently dipping Palaeozoic limestones have caused a dendritic drainage pattern with creeks flowing in steep-walled canyons 1000 to 2000 feet below ridge tops. Average relief here varies from 1500 to 2000 feet with maximum local relief of 3700 feet at Devils Head (Figure 2), the highest point in this belt (elevation 9174 feet).

The western Front Range comprises Palaeozoic strata dipping 20-35 degrees west and has a topographic expression more typical of the Front Ranges in other areas, with pronounced dip-slopes along the east side of the upper Ghost River valley. Local relief averages 2000 to 3000 feet up to a maximum of 4900 feet at Mount Costigan (elevation 9775 feet). North of the transverse valley of Ghost River, most tributary drainage is obsequent into upper Ghost River. Near the east-west portion of Ghost River, Devils Gap and South Ghost River, drainage is largely subsequent.

The interior of the Front Range within the map-area is drained by Waiparous Creek, Ghost River, Ghost Lakes and Lake Minnewanka, and South Ghost River. The northern and northeastern slopes of the Front Range are drained by tributaries of Burnt Timber and Fallentimber Creeks, both of which debouch into Red Deer River

northeast of the map-area. Waiparous Creek and the two forks of Ghost River flow easterly to Bow River, with the exception of that portion of Ghost River which is diverted to empty into Lake Minnewanka and eventually reaches Bow River near Banff.

The north-northwest valley of the upper Ghost River is cut in soft Mesozoic siltstones and shales that form the core of a doubly-plunging syncline west of the Exshaw thrust fault. The transverse portion of Ghost River valley is controlled by the Ghost River fault, which extends for five miles oblique to the strike of the Front Range Palaeozoic rocks. No obvious explanation for the linearity of the Devils Gap can be given.

Topography is controlled markedly by the bedrock formations in the eastern portion of the Front Range, irrespective of the structural elevation of these units. Valley walls are formed by sheer cliffs of Cambrian limestone and are capped by less resistant limestones and shales which underlie gentle slopes on the higher portions of the ridges (Plate 3A). In the western belt, subsequent drainage is governed by alternating resistant limestones and easily eroded shales. North of Ghost River, the general southerly plunge of the Palaeozoic beds is reflected by a gradual decrease in elevation of transverse ridges from north to south.

GENERAL GEOLOGY

North and Henderson (1954, p. 17) have divided the Rocky Mountains into four sub-provinces. From west to east these are: Western Ranges, Main Ranges, Front Ranges, and Foothills. The Ghost River map-area straddles the McConnell thrust fault which forms the boundary between the Front Ranges and Foothills sub-provinces. A pronounced salient in the Mountain front, resulting from the structurally low position of the fault at this latitude, occupies a major portion of the map-area. A westerly dipping homocline of Palaeozoic rocks lies west of this protrusion, and is separated from it by the Costigan thrust fault (Figure 2).

Middle Cambrian and Upper Devonian strata with gentle dips overlie the McConnell thrust in the salient and form a relatively thin sub-horizontal panel of rocks herein referred to as the Orient block* of the McConnell thrust sheet.

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* A problem regarding the terminology of thrust fault structures arises in the Ghost River area. General practice is to assign a name to a large thrust fault (e.g. McConnell Thrust, Lewis overthrust) and apply the same name to the strata above the fault (e.g. McConnell thrust sheet, Lewis thrust sheet). Exceptions to this system have been incorporated in the literature (e.g. Highwood thrust sheet overlying the Outwest fault) but these are to be avoided if possible since the use of different names for parts of the same structure can only result in confusion when the structures are referred to.

In the Ghost River area, the main body of Paleozoic rocks is divided longitudinally by a major fault or fault zone, herein named the Costigan thrust. Strata above (i.e. west of) this fault should be properly termed the "Costigan thrust sheet". Rocks east of (i.e. under) the Costigan thrust, are in turn underlain by the McConnell thrust fault and should properly be assigned to the "McConnell thrust sheet".

The problem arises due to the fact that the Costigan fault is a branch of the McConnell thrust and has a definite western limit. North of Burnt Timber Creek, on South Ghost River, and at several places south of the map-area, recent erosion has removed that part

The Costigan block includes strata of Middle Cambrian and Upper Devonian to Triassic ages. This and the western part of the Orient block are cut by the Ghost River tear fault, which terminates to the east against a small thrust fault in the latter. West of the Costigan block, and separated from it by the Exshaw fault, is the Exshaw thrust sheet, containing beds of Mississippian and younger ages.

The eastern edge of the Orient block contains the Black Rock belt of small imbricate thrust faults. South of the Ghost River tear fault, the Costigan thrust is replaced by a thrust fault zone containing three or four relatively large faults. Little plunge is present on the Costigan and Exshaw structures, however the Orient block contains several small folds and has the general form of a broad doubly plunging syncline. The west limb is overridden by the Costigan thrust.

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of the McConnell thrust sheet lying east of the Costigan fault, and has exposed the part of the McConnell thrust that lies west of its junction with the Costigan fault. It follows then, that in these deeply eroded areas, the "Costigan thrust sheet" is underlain by the McConnell thrust. To avoid this confusing terminology, and to allow of separate treatment of the strata above the Costigan fault (which form a significant part of the structure of the map-area), it is proposed to subdivide the strata underlain by the McConnell thrust into two units, informally referred to as "blocks". The McConnell thrust sheet in the Ghost River area will then be divided by the Costigan fault into a western "Costigan block" and an eastern "Orient block", the latter named after Orient Point, and limited to the east by the outcrop of the McConnell thrust. In areas where the Orient block has been completely removed by erosion, (e.g. on Bow River or north of Burnt Timber Creek) beds above the McConnell thrust may be referred to as the Costigan block, or simply as the McConnell thrust sheet. Remnants of the Orient block are presently restricted to the area between Bow River and Burnt Timber Creek (Figure 2).

This terminology also has the advantage that other structures west of the outcrop of the McConnell thrust (e.g. the Exshaw thrust sheet), if proven in the future to be portions of the McConnell thrust sheet may be described as "blocks" of the McConnell sheet. Dahlstrom and Henderson (1959, p. 53) for example, suggest that many of the Front Range thrust faults are branches of the McConnell thrust.

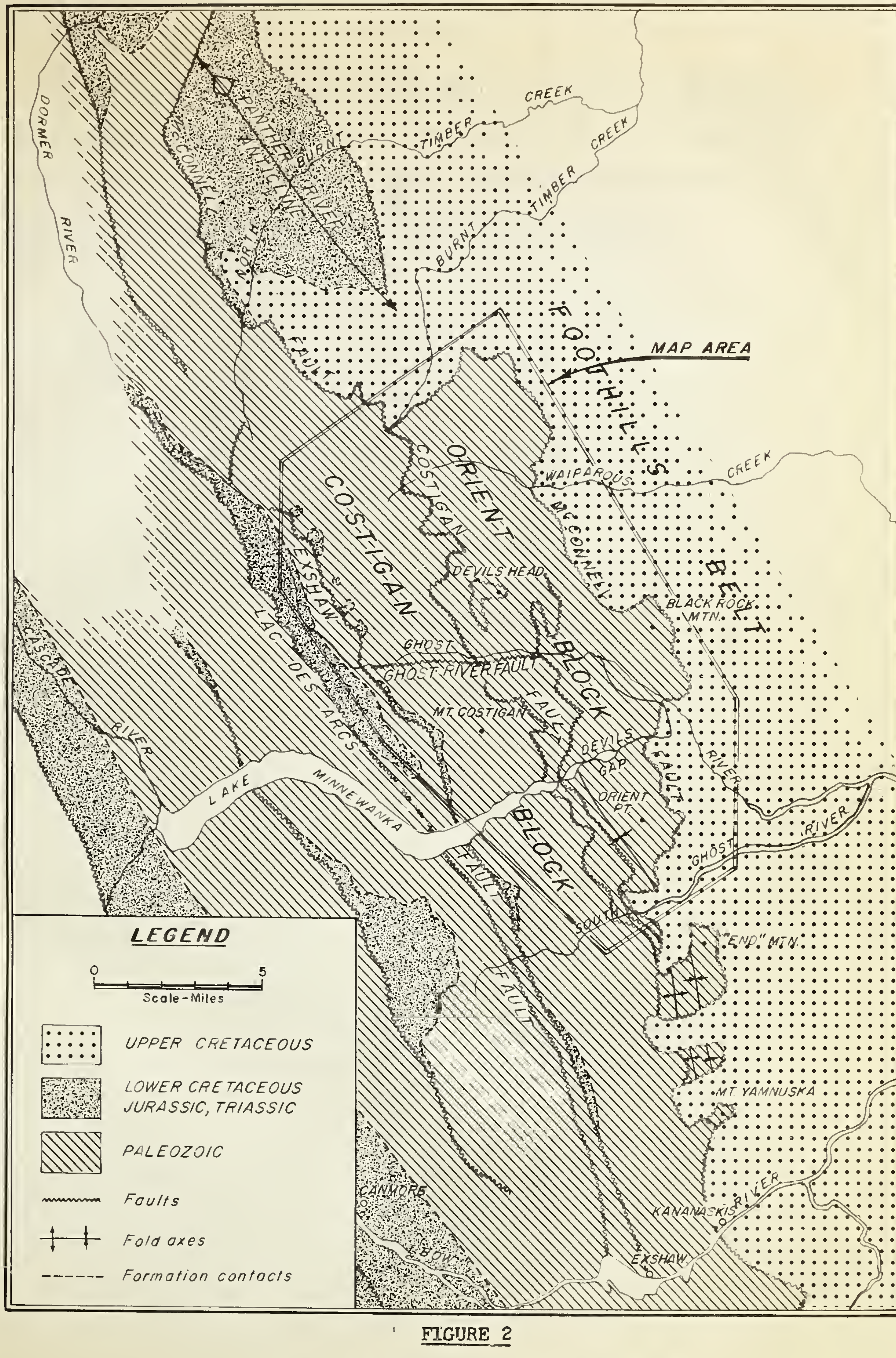


FIGURE 2

INDEX MAP SHOWING REGIONAL STRUCTURE
AND LOCATION OF GHOST RIVER AREA.

North of the Ghost River area, a pronounced recession in the Mountain front is occupied by the Panther River anticline and associated thrust fault (Hunt, 1956). This structure plunges southerly beneath the McConnell thrust in the map-area.

STRATIGRAPHY

The stratigraphic section exposed in the Ghost River and adjacent areas is given in the following Table of Formations:

Table of Formations

Age	Formation	Lithology	Thickness
Upper Cretaceous	Belly River fm.	sandstone, shale	3000+
	Wapiabi fm.	shale	500+
	*Cardium fm.	sandstone	
	*Blackstone fm.	shale	
Lower Cretaceous	*Blairmore grp.	sandstone, shale	
Jurassic	*Kootenay fm.	sandstone, shale	
	*Fernie group	shale	
Triassic	Spray River fm.	siltstone, dolomite	100
Perm Penna.	Rocky Mountain grp.	sandstone, dolomite, chert	330
Mississippian	Rundle group.	limestone, dolomite, shale	1700
	Banff fm.	limestone, shale	870
Upper Devonian	Exshaw fm.	shale	30
	Palliser fm.	limestone, dolomite	820
	Alexo fm.	dolomite, siltstone	150
	Fairholme grp.	dolomite	1050
Devonian	Ghost River fm.	dolomite	360
Middle Cambrian	Pika? fm.	limestone, shale	300
	Eldon fm.	limestone, dolomite	860
	Stephen fm.	shale, limestone	100
	Upper Cathedral fm.	limestone	600
	Lower Cathedral fm. (units 1-3)	shale, sandstone, limestone	260+

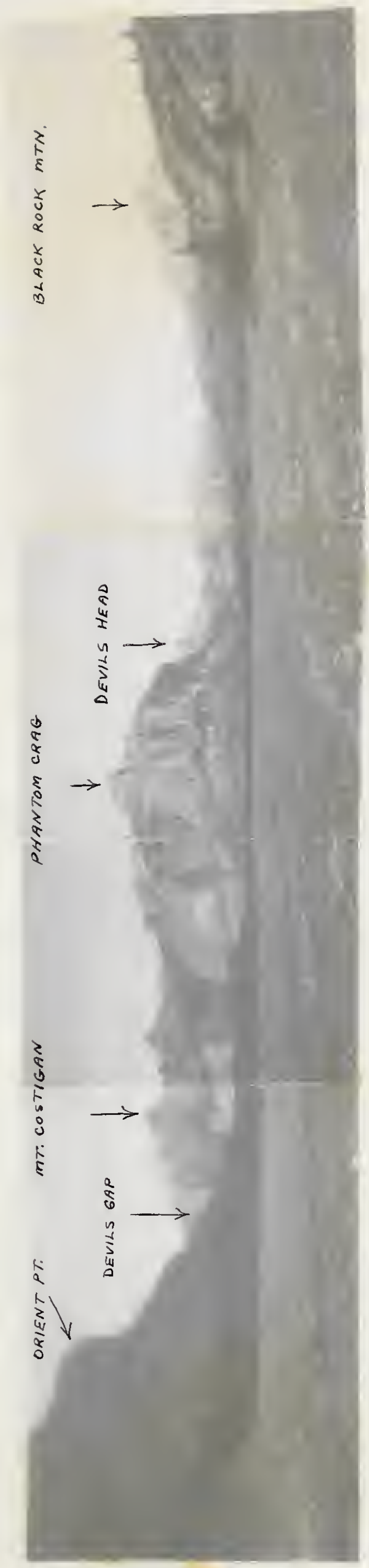
* Not present in the map-area.

Rocks ranging in age from Middle Cambrian to Upper Cretaceous are exposed in the Ghost River area. The major structure of map-area, the McConnell fault, causes omission of part of the normal stratigraphic section and effectively divides the area into two

Description of Plates

Plate 1

Ghost River, Costigan and Orient Blocks of McConnell thrust sheet, Black Rock belt.


ORIENT PT.
DEVILS GAP
MT. COSTIGAN
PHANTOM CRAG
DEVILS HEAD
BLACK ROCK MTN.

Descriptions of Plates

Plate 1

Ghost River, Costigan and Orient Slabs of McConnell thrust sheet, Black Rock unit.

dissimilar stratigraphic areas. Below (east of) the McConnell fault, non-resistant shales and sandstones of the Upper Cretaceous Wapiabi and Belly River formations are sparingly exposed in the Foothills belt. Above the McConnell fault, and west of its surface trace, rocks of Middle Cambrian, Devonian, Mississippian, Pennsylvanian, Permian and Triassic ages occupy most of the map-area. Jurassic and Lower Cretaceous strata, and the lower part of the Upper Cretaceous, do not outcrop within the Ghost River area but are exposed north of Burnt Timber Creek on the Panther River anticline (Hunt, 1956).

This is the standard section for this part of the Front Ranges and Foothills and has been described by various writers. Most of the post-Cambrian formations were examined in only enough detail to establish the structure of the area, and since the various units are readily identified on aerial photographs and from a distance on the ground, and are distinctive in relatively small exposures, many of these beds were not traversed in the homocline of the Costigan thrust sheet.

The Cambrian section required more attention as no adequate description was available for the Ghost River area and because of the presence of a section of unusual thickness for the Front Range. Subdivision of the Cambrian sequence was deemed necessary as a prerequisite to structural mapping of the Ghost River area. A natural breakdown is present, the various formations permitting of reasonable correlation with Cambrian units in the Field, British Columbia area. Descriptions of the various units follow.

Lower Cathedral Formation

The oldest beds exposed in the area comprise a few hundred feet of reddish brown weathering interbedded sandstone and shale of Middle Cambrian age equivalent to the lower part of the Cathedral formation of the Field, British Columbia area.

Distribution

These sandstones and shales are recessive and are badly covered throughout the area. In the Orient block, this unit is intermittently exposed from the head of Burnt Timber Creek to Orient Point between the cliff-forming limestones of the Upper Cathedral formation and the underlying McConnell fault. Small areas of outcrop appear above the Costigan fault at the source of Burnt Timber and Waiparous Creeks, and on Ghost River near the centre of the Orient block. Wherever seen in the area, the Lower Cathedral is partially covered and badly folded and faulted so that no complete thickness was obtained. Three miles north of Waiparous Creek, a reasonably undisturbed exposure has a thickness slightly in excess of 200 feet with the base not exposed.

General Description

Shale predominates in the Lower Cathedral formation and forms about 75 percent of the section. Sandstone and limestone, although prominent, comprise a relatively small portion of this unit. The shales are olive grey, fissile, brittle and are frequently highly slickensided. Sandstone occurs in beds averaging 1 inch in thickness and consists mainly of fairly well rounded, well sorted quartz with quartz, dolomite or iron oxide cement. Limestones present near the top of this unit are mainly calcarenites and form 1 inch thick beds in the shale.

Lower Cathedral formation may be conveniently subdivided into three lithologically distinct units which are numbered from the base upwards. Unit 1 was observed only on Ghost River and consists predominantly of medium to thick bedded sandstones with minor shale. Unit 2, more widespread, is shale with thin sandstone interbeds, and Unit 3, shale and limestone.

Unit 1

On the south side of Ghost River, close to the Ghost River fault, medium to thick bedded sandstones interbedded with minor shale dip steeply west in a series of outcrops. One exposure of these beds was found to be in excess of 100 feet thick, and depending on the amount of faulting between outcrops, the thickness may be several times this figure. The sandstones weather pale brown (5YR5/2), yellowish grey (5Y7/2) and greyish red (5R4/2); are very fine grained to coarse grained; light brown (5YR5/6), yellowish grey (5Y7/2), and greyish red (5R4/2); medium to thick bedded; sub rounded to rounded; moderately well sorted; mostly quartz; with some irregular, soft shale laminae, scattered glauconite grains and irregular segregations of calcite or dolomite in the normal quartz or iron oxide cement. Shales in unit 1 weather light brown (5YR5/6), are greyish olive (10Y4/2), brittle, silty, non calcareous; with irregular bedding surfaces and "worm trails".

Since this unit was observed only on Ghost River and is lithologically unlike higher beds in the Lower Cathedral formation, it is considered to represent the oldest rocks of the area and to underlie shale and sandstone of unit 2.

Unit 2

Shale with interbedded thin sandstone beds outcrops on Ghost River near the Ghost River fault at a higher elevation than the sandstones in unit 1 of the Lower Cathedral formation. Faulting obscured the stratigraphic relationships between units 1 and 2. More than 90 feet of partially contorted shales with interbedded sandstone and shaly sandstone that underlie shale and limestone of unit 3 with apparent conformity overlie exposures of unit 1 on Ghost River and are separated from them by abrupt changes in attitude and small-scale faulting.

Throughout unit 2 the shale weathers light brown (5YR5/6), is greyish olive (10Y4/2), non calcareous, lustrous, brittle, with irregular bedding surfaces; contains silt, disseminated dark material, and scattered trilobite fragments. Sandstones near the top of the unit weather dark yellowish orange (10YR6/6), to pale yellowish brown (10YR6/2), are moderate brown (5YR3/4), to pale yellowish brown (10YR6/2), soft friable, argillaceous, calcareous, very fine grained, mainly sub-rounded to sub-angular quartz with quartz cement and segregations of iron oxide, some of which have calcite centers.

Lower in this exposure a similar sandstone contains scattered, well rounded, black, light grey and green rock fragments averaging 0.25 mm. in diameter. Much of this sandstone is more quartzitic with less calcite. Irregular greyish olive (10Y4/2), shale partings are ubiquitous. A 3 inch thick bed at the top of unit 2 consists of yellowish grey (5Y7/2) weathering medium light grey (N6), hard, finely fractured, siliceous rock with very fine laminae and segregations of calcite. "Worm trails" are common in sandstones throughout this section.

Unit 2 outcrops sporadically near the saddle between "Sheep Meadow" and "End" Mountains and on the west flank of "Sheep Meadow" Mountain north of Waiparous Creek where the shales and sandstones are highly folded. Sandstones of this unit outcropping at the Ghost River Diversion vary from fine to coarse grained, are sub rounded, moderately well sorted, mainly quartz with some irregular, 1 mm. diameter segregations of euhedral dolomite, and in some beds scattered rock fragments up to 1 mm. thick to 100 mm. long. Sandstones in unit 2 are generally less well rounded, finer grained, and less well sorted than those in the underlying unit.

Unit 3

A poorly exposed section of the upper beds of the Lower Cathedral Formation is exposed on a small creek draining to eastern slopes of Orient Point. In descending order this consists of:

UPPER CATHEDRAL FORMATION

60+ LIMESTONE - dolomitic, massive.

LOWER CATHEDRAL FORMATION

30-60 SHALE - light olive grey (5Y5/2), waxy, non-calcareous, fissile; with 1 inch thick beds of dark grey (N3), limestone of trilobite fragments in a clear calcite matrix. Other limestone bands are finely crystalline with pellets, scattered trilobite fragments, irregular transverse shale partings and disseminated pyrite. Rare beds of limestone conglomerate are present. The limestone beds tend to be nodular, thicken locally to three inches, and become more closely spaced towards the top of this unit (1-2 inches apart).

10-30 COVERED INTERVAL

0-10 LIMESTONE - weathering greyish orange (10YR7/4), dark grey (N3), finely crystalline with irregular dolomite segregations 50-100 mm. in size, some of which are tubular while others have stylolitic boundaries with the limestone. The dolomite is pale yellowish brown (10YR6/2), medium crystalline, euhedral. Both longitudinal and transverse stylolites are present in the limestone, as well as white calcite veins. Beds are 2-6 inches thick, with rough, irregular bedding surfaces.

- base of section -

Sixty feet of this upper unit of the Lower Cathedral formation outcrop above the McConnell fault on a south-flowing tributary of Waiparous Creek and intermittent poor exposures are present as far as the eastern headwaters of this creek. Strata thought to be equivalent to unit 3 outcrop on the south bank of Ghost River adjacent to the Ghost River fault. At this locality, there are approximately 70 feet of alternating thin bedded limestone weathering dark yellowish orange (10YR6/6), dark grey (N3) argillaceous with trilobite fragments mostly about 1 mm. in length but up to 100 mm. in a matrix of clear calcite, containing scattered olive grey shale flakes (2 mm. by 400 mm.); and shale weathering dusky yellow (5Y6/4), light olive grey (5Y5/2), to olive grey (5Y4/1), fissile, waxy in part, cleaved, slightly calcareous, to non-calcareous, with 1/4 mm. diameter segregations of dark material and scattered trilobite fragments. Some lenticular limestone conglomerate bands are present. These beds immediately overlie shale and sandstone referable to unit 2 of the Lower Cathedral formation.

This upper unit may be represented by limestone and shale at the north end of a badly disturbed exposure at the Ghost River Diversion, and folded dolomitic limestones of this unit outcrop above the McConnell fault on Waiparous Creek.

Contacts

The transition from this formation to massive limestones of the Upper Cathedral is abrupt and apparently conformable but the actual contact was covered in all exposures examined. The base of the Lower Cathedral is a fault contact throughout the area.

Age

Recognizable fossils consist only of the above mentioned "worm trails" in units 1 and 2 of the Lower Cathedral. The Upper limestones of unit 3 contain trilobites which have been identified by C.L. Balk as follows:

Collection 60F26 - Ghost River, three miles south of the top of Black Rock Mountain.

Vanuxemella nortia Walcott

Abertella fragments

Collection 60F57 - One mile east-northeast of the top of Orient Point.

Vanuxemella nortia Walcott

cf. *Albertella nitida* Resser

Both collections, according to Dr. Balk, belong in the Middle Cambrian Albertella zone. This fauna characterizes the Ross Lake Shale member of the Cathedral formation in the type areas near Field (Rasetti, 1951, p. 70) where it occurs between the *Plagiura-Kochaspis* zone of the Mount Whyte formation and the overlying

Glossopleura zone of the Stephen formation.

In the type area, the Ross Lake Shale is not referred to either the upper or lower parts of the Cathedral formation (Rasetti, 1951, p. 69), and may be separable as a distinct member in the Ghost River area. However, since the lithology and thickness of the *Albertella* zone in the Ghost River area does not coincide too closely with that in the type area, and since these beds at Ghost River are lithologically similar to the underlying strata, they are included with the lower shale-sandstone units (1 and 2) for mapping purposes, and the unfossiliferous lower units are considered, on stratigraphic position, as correlatives of the Lower Cathedral formation (Figure 3).

Correlation

Correlation of the Lower Cathedral formation with the type area is indicated above. A correlation may also be made with the Cambrian rocks underlying the central Alberta plains where the *Albertella* zone has been reported from brown shale in California Standard Parkland No. 4-12 well, (Lsd. 4, Sec. 12, Twp. 15, Rge. 27, W4 Meridian) overlying coarsely rounded basal clastics (Raasch and Campau, 1957, p. 140; Van Hees, 1959, p. 77). This zone has been extrapolated by van Hees over a large part of western Alberta (Figure 3).

Upper Cathedral Formation

Approximately 600 feet of massive, cliff forming dolomitic limestone referable to the upper part of the Middle Cambrian Cathedral formation overlie the shales, sandstones and limestones of the Lower Cathedral formation.

Distribution

An outcrop belt of this formation overlies that of the Lower Cathedral along the eastern portion of the McConnell thrust sheet. Inliers occur in the Orient block on Waiparous Creek and in the cores of anticlinal structures on Ghost River. In the Costigan block, a continuous belt of this unit overlies the Costigan fault from Ghost River to and beyond the north boundary of the map-area, and a discontinuous faulted outcrop belt extends south from this river at least as far as South Ghost River. Much of Black Rock Mountain consists of limestones of the Upper Cathedral formation repeated by several thrust faults. Normally, the Upper Cathedral limestone forms a relatively low broken cliff between recessive Stephen shales and the underlying Lower Cathedral shales.

General Description

The Upper Cathedral formation consists of uniform, thick bedded to massive, dark grey limestones with brown dolomite segregations that weather in relief on the surface. Microscopically, the rock consists of finely crystalline limestone with pellets of various sizes and fine stylolitic shale partings that trend in all directions. Patches and veins of white coarsely crystalline calcite are common as well as variable amounts of euhedral dolomite, in distinct bands and disseminated through the limestone. Near the middle of the unit a dark grey shale about ten feet thick, weathers recessively and is useful as a marker horizon. This shale grades through a few feet of thinly bedded, rusty weathering dolomitic limestones or brown, laminated, non-dolomitic limestones into the massive limestones above and below.

Near the north end of the map-area, the top five feet of the Upper Cathedral consist of a light grey weathering, brown, very finely crystalline, laminated limestone, which increases in thickness to the south, until, near South Ghost River, it forms about 50 percent of the upper hundred feet of the formation.

Contacts

The contact with the Lower Cathedral is apparently conformable. The upper contact is a distinctive sharp break between massive limestones of the Upper Cathedral and thin bedded, rusty weathering dolomitic limestone and shales of the overlying Stephen formation.

Age

Although trilobite fragments were observed at the top of the unit and in the thin recessive unit in the middle of the Upper Cathedral, identifiable fossils were not collected. The formation belongs to an unnamed zone between the Middle Cambrian *Albertella* and *Glossopleura* zones of the type area (Rasetti, 1951, p. 69).

Correlation

The above-mentioned zone is represented in the Field area by the Upper Cathedral formation. Equivalents of this unit are present in the subsurface of central Alberta where 300 feet of limestone and argillaceous limestone penetrated in California Standard Parkland 4-12 well have been correlated with the Upper Cathedral by Raasch and Campau (1957). Van Hees has extended this correlation over much of south central Alberta (1959, p. 77).

Stephen Formation

In the Ghost River area the Stephen formation is a prominent recessive rusty weathering bench between the underlying Upper Cathedral and the overlying Eldon limestone. It consists of limestone and shale with a thickness of about 100 feet.

Distribution

This formation outcrops in an almost continuous band above the McConnell thrust from the head of Burnt Timber Creek to Orient Point, and above the Costigan fault for the length of the map-area. Faulted bands of Stephen occur in the Orient block on Black Rock Mountain, north of Waiparous Creek, and in Devils Gap. Inliers are present near the head of Burnt Timber Creek on two tributaries of Waiparous Creek, and on Ghost River.

General Description

A large part of the Stephen formation consists of argillaceous limestone and the unit includes a variety of minor lithological types. Wherever examined, a three-fold subdivision is apparent into upper and lower limestones and a medial shale, each of which is about 30 feet thick. A representative section, measured in the Costigan block south of Ghost River is, in descending order:

ELDON FORMATION

89+ LIMESTONE - weathers light grey; finely crystalline; dark grey; medium bedded; with irregular bands of medium crystalline dolomite.

STEPHEN FORMATION

71-89 * LIMESTONE - weathers moderate yellowish brown (10YR5/4);

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* Indicates that samples were examined with a binocular microscope.

finely crystalline; dark grey (N3); thin bedded; with irregular 50 mm. thick laminae of brown euhedral medium crystalline dolomite, with minor argillaceous material and pyrite. Laminae weather dark yellowish orange (10YR6/6) and are dusky yellow (5Y6/4). Grades with thicker bedding onto the overlying unit.

65-71 * SHALE - weathers yellowish grey (5Y7/2); non-calcareous; olive grey (5Y4/1); blocky; hard; cleaved; slickensided with fine segregations of dark material.

63-65 * LIMESTONE - weathers yellowish grey (5Y7/2); finely crystalline; medium light grey (N6); thick bedded; with trilobite fragments and glauconite (up to 25%); contains pebbles up to 500 mm. in length of very finely crystalline limestone with scattered pyrite. Thin argillaceous partings surround the pebbles.

50-63 * SHALE - weathers moderate yellowish brown (10YR5/4); fissile; greyish green (10GY5/2); slightly calcareous; cleaved; slickensided; with scattered rusty segregations.

28-50 * SHALE - weathers greyish orange (10YR7/4); fissile; greyish red (5R4/2); and dusky yellow-green (5GY5/2); weathering yellowish grey (5Y7/2); brittle; non-calcareous slickensided; the green phase is silty with dark segregations and some pyrite; with a few 1 inch thick beds of limestone; weathering greyish orange (10YR7/4); light grey (N7); oolitic; ooliths average 1/2 mm. diameter in very finely crystalline clear calcite matrix; fine green irregular shale partings and transverse veins of white calcite. Occasional finely crystalline pellets. Ooliths project in

relief at limestone-shale contacts.

27-28 * LIMESTONE CONGLOMERATE - weathers dark grey (N3); one three inch thick bed; medium dark grey (N4); pebbles finely crystalline; sub-rounded; tubular; 2 mm. to 2 inches in length; with weathered edges; matrix is coarsely crystalline white calcite partially replaced by medium crystalline euhedral dolomite; scattered pyrite; some pebbles appear to be fragments of limestone conglomerate; some white calcite veins.

22-27 * LIMESTONE - weathers light olive grey (5Y5/2)); finely crystalline; medium dark grey (N4); thin bedded; with irregular laminae 1 mm. to 100 mm. thick of subhedral medium crystalline dolomite; some trilobite fragments; limestone has scattered medium crystalline subhedral dolomite and pyrite segregations. Unit becomes argillaceous towards the base.

21-22 LIMESTONE - weathers light olive grey (5Y6/1); finely crystalline; medium grey (N5); argillaceous; laminated; cleaved; with fossil remains and pyrite; partially subhedral dolomite.

13-21 LIMESTONE - finely crystalline, similar to 22-27 above.

8-13 * LIMESTONE - finely crystalline, similar to 21-22.

0-8 * LIMESTONE - weathers yellowish grey (5Y7/2); finely crystalline; medium dark grey (N4); thin bedded; nodular; with pellets; fossil fragments; pyrite; 1 mm. to 5 mm. thick irregular laminae of argillaceous dolomite; interbedded with argillaceous limestone similar to 21-22.

UPPER CATHEDRAL FORMATION

LIMESTONE - weathers medium light grey (N6); finely crystalline; dark grey (N3); thin to thick bedded; with pellets; fossil fragments; pyrite; with irregular bands 100 to 200 mm. thick of coarsely crystalline fibrous calcite.

Most of the units delimited in this section are recognizable throughout the map area. In particular the limestone conglomerate (27 to 28 feet) was found in all sections examined and varies from 4 inches to 1 foot in thickness.

At two localities north of the Ghost River the middle shale member is less than the usual thickness of 30 feet. Poor exposure prevented determination of the cause of thinning, although local evidence suggests it may be tectonic.

Contacts

Although the lower contact is very pronounced, the upper is gradational and for mapping purposes has been taken at the highest occurrence of shale in the Stephen formation.

Age

The lowermost 10 feet of the Stephen formation frequently abound fossils, some bedding planes being covered with disarticulated trilobite remains. Dr. Balk has identified the following trilobites from this unit:

Collection 60F37 - Quarry on the Ghost River 2½ miles south-southwest of the top of Black Rock Mountain.

Glossopleura cf. *boccar* (Walcott)

Alolistocare cf. *modestum*

Collection 60F113 - Waiparous Creek, 1 mile west of the McConnell fault.

Glossopleura sp.

Collection 60F179 - Ghost River, in immediate footwall of Costigan fault.

Glossopleura cf. boccar (Walcott)

Collection 60F334 - West flank of Black Rock Mountain, elevation 7400 feet.

Glossopleura cf. belesis (Walcott)

Glossopleura sp.

Mexicella sp.

Collection 60F339 - West flank of Black Rock Mountain, elevation 7400 feet.

Glossopleura sp., probably boccar (Walcott)

Alokistocare sp. undet.

Collection 60F398 - Near top of "Sheep Meadow" Mountain.

Glossopleura boccar (Walcott)

Kootenia sp.

Alokistocare sp.

Collection 60F468 - Ghost River, 2 miles south of Devils Head

Glossopleura sp.

Dr. Balk states that these collections belong to the Glossopleura zone. This is the lowest zone of the type Stephen formation in the Field area (Rasetti, 1951, p. 97). The type Upper Stephen Bathyuriscus - Elrathina zone is not represented in collections from the Ghost River area.

Correlation

In addition to the common development of the Glossopleura fauna in the Field area, correlatives of the Lower Stephen formation

have been reported from the Plains region of Alberta by Raasch and Campau (1957, p. 142), van Hees (1959, p. 75) and Hutchinson (1960, p. 137) where both the Lower Stephen *Glossopleura* and Upper Stephen *Bathyuriscus* - *Elrathina* zones occur in shale between limestones of the Eldon and Upper Cathedral formations.

Eldon Formation

Some of the most spectacular scenery in the eastern part of the Ghost River map-area is provided by Middle Cambrian Eldon limestones. Most of the valley walls in the Orient block consist of gently dipping beds of this formation, which weather to form near-vertical cliffs that rise almost 1000 feet between less resistant strata of the Stephen and Pika? formations (Plate 2A)

Distribution

A large part of the Orient block is formed by the Eldon formation. Continuous outcrops extend up most of the valleys and form the bases of many of the mountains. In the Costigan block, the Eldon formation extends the length of the map-area, forming "basins" at the headwaters of Burnt Timber and Waiparous Creeks, as well as the first south tributary of Waiparous Creek and the large south-flowing tributary of Ghost River. The upper cliffs of Castle Peak and Devils Head are limestones of this formation. South of Devils Gap, this unit is folded and faulted to form the bulk of the Costigan fault zone.

General Description

Wherever examined, the Eldon formation was found to be a uniform, rather thinly bedded, massive weathering dark grey limestone.

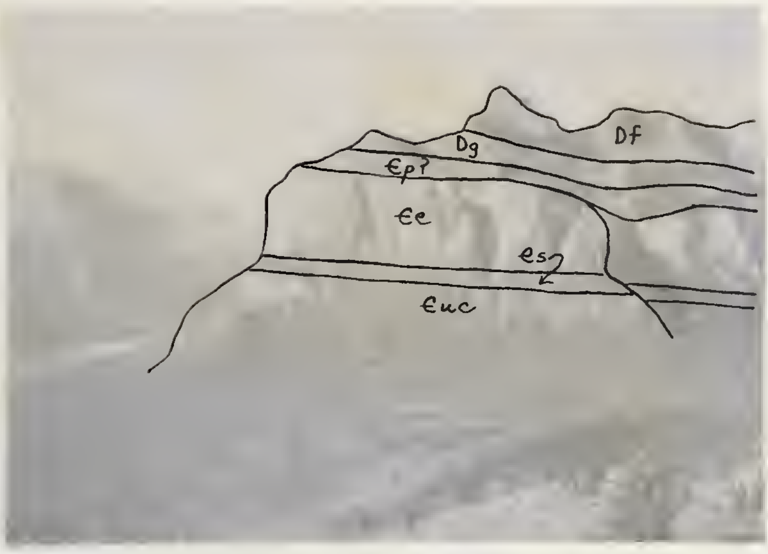
Description of Plates

Plate 2

A - Stratigraphic section exposed on Orient block of McConnell thrust sheet, east limb of End Mountain syncline (looking south).

B - Stratigraphic section exposed on Orient block of McConnell thrust sheet (looking southeast across Burnt Timber Creek).

C - Exposure of McConnell fault at northern limit of Orient block of McConnell thrust sheet (looking northeast).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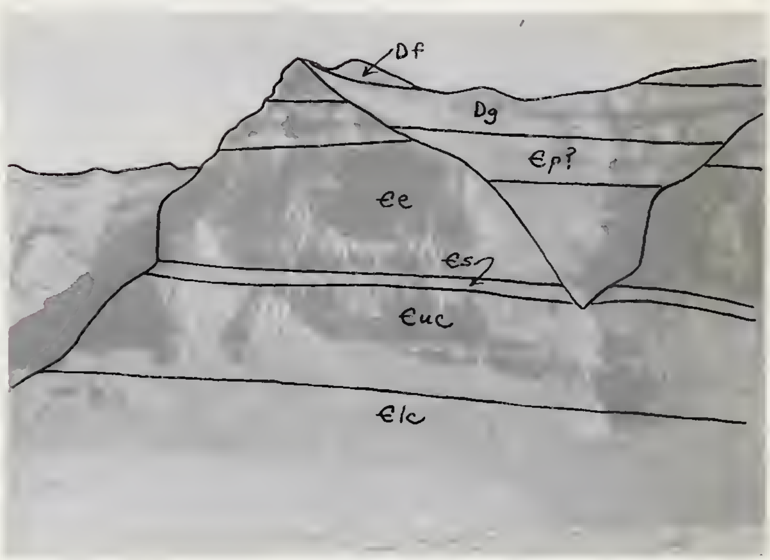
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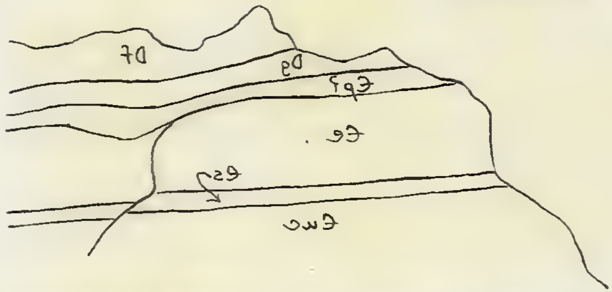
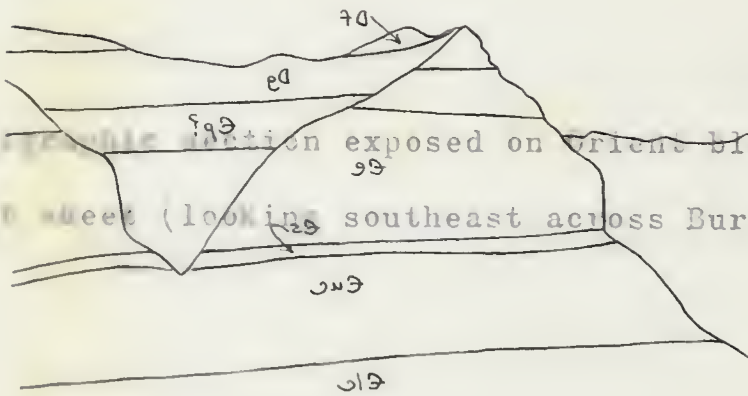
Description of Plates

Plate 2

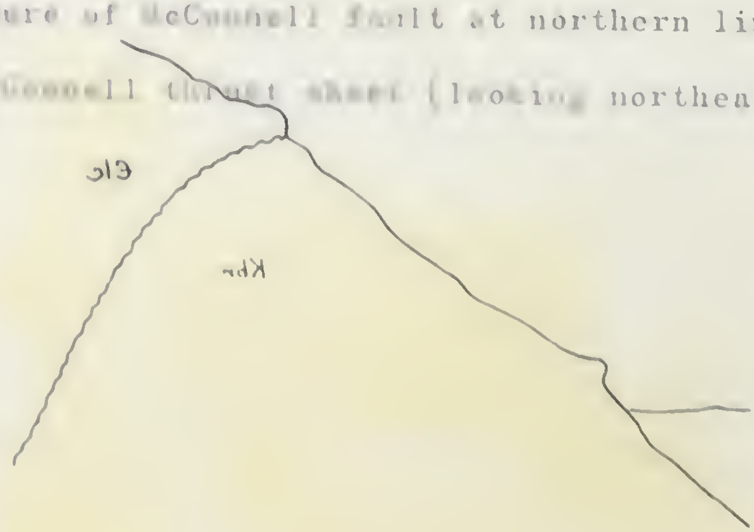


A - Stratigraphic section exposed on Orient block of McConnell thrust sheet: west limb of End Mountain syncline (looking south).



B - Stratigraphic section exposed on Orient block of McConnell thrust sheet (looking southeast across Burnt Timber Creek).

C - Exposure of McConnell fault at northern limit of Orient block of McConnell thrust sheet (looking northeast).



Irregular dolomite bands at intervals of a few inches or less weather in relief to give the surface an extremely rough texture. Under the binocular microscope the limestones are very finely crystalline, with pellets and medium crystalline euhedral dolomite both as distinct bands and disseminated through the limestone. Fracturing and calcite veining is common. The thickness appears uniform throughout the map-area and is close to 850 feet with no mappable subdivisions being apparent. A partially covered section of the Eldon formation west of the Ghost River Diversion, is typical of this unit. In descending order this consists of:

PIKA? FORMATION

860+ LIMESTONE - thinly bedded with irregular dolomite laminae.

ELDON FORMATION

500-860 LIMESTONE - weathers medium grey (N5); dark grey (N3); thick bedded to massive, very finely crystalline; with pellets 1-5 mm. diameter of very finely crystalline brown limestone. Some composite pellets; and larger pellets have spherical 1 mm. diameter dark, crystalline calcite oolites?. Disseminated brown euhedral medium crystalline dolomite forms up to 10 percent of the rock and is concentrated in the matrix. Some coarsely crystalline clear calcite spheres 0.5 to 2 mm. diameter are present as well as irregular laminae of brown euhedral dolomite parallel to the bedding.

300-500 LIMESTONE - weathers medium grey (N5); thick bedded (1.5 feet); dark grey (N3); with irregular, 0.5 mm. dolomite bands parallel and transverse to bedding. Some isolated

patches of dolomite 200 mm. diameter. Lithology is similar to 0-300 feet.

0-300 LIMESTONE - medium to thick bedded; weathers medium grey (N5) very finely crystalline; dark grey (N3); with 1 to 10 percent euhedral brown coarsely crystalline disseminated dolomite; with irregular laminae parallel to bedding, 1 mm. to 150 mm. thick at intervals of 100 to 300 mm. of dolomite; olive grey (5Y4/1); weathers light olive grey (5Y5/2); euhedral to subhedral; medium crystalline; some laminae with sharp boundaries, others diffuse. Occasional spherical bodies 2 mm. diameter of coarsely crystalline subhedral clear calcite with vague boundaries, some of which have patches of medium crystalline euhedral dolomite.

STEPHEN FORMATION

LIMESTONE - thin bedded, very finely crystalline, with irregular laminae.

Contacts

Both upper and lower contacts of the Eldon are gradational in the Ghost River area. Downwards, the unit becomes more thinly and regularly bedded and grades into rusty weathering limestones more typical of the Stephen formation over an interval of several tens of feet. This transitional zone has been arbitrarily excluded from the Stephen formation. In the Field area, Rasetti (1951, p. 74) has reported a similar transition between the two formations, and he recommends including the transition zone in the Eldon formation, a practice not followed by his predecessors.

Although the contact with the overlying Pika? formation appears distinct at a distance, it is difficult to establish in small outcrops on the basis of lithology. Dolomitic limestones in the upper Eldon formation become more thinly bedded and lithologic types similar to typical Eldon limestones recur at intervals in the Pika? formation. The contact has been mapped at the first appearance of argillaceous beds or limestone conglomerate above the usual Eldon lithology. In partially covered sections, this contact is very difficult to place and this feature is probably responsible for some writers' practice of referring to the Pika as "Upper Eldon" (deWit, 1956) or as the "Pika member" (Raasch and Campau, 1957) of the Eldon formation. This latter practice may eventually prove desirable but any formal change from the original designation of this unit as "Pika formation" has not been published to date.

Age

One large trilobite apparently derived from the Eldon formation was collected in talus, but was not identifiable. The Eldon is assumed to be Middle Cambrian on the basis of its stratigraphic position.

Correlation

Most of this unit is correlated on lithology and stratigraphic position with the type Eldon formation of the Field area. Coeval strata are also reported from the Alberta plains by Raasch and Campau (1957) and van Hees (1959).

Pika? Formation

Beds questionably referred to the Middle Cambrian Pika formation overlie massive Eldon limestones throughout the Ghost

River area, and are in turn overlain by dolomites of the Ghost River formation. Considerable uncertainty exists regarding the age of this unit to the south of the map-area.

Distribution

Limestones of the Pika? formation are present in the eastern portion of the map-area on rubble covered slopes and benches above the sheer Eldon cliffs. This unit, with the overlying Ghost River formation, is charastically badly covered and no complete section was examined in the area. In the Costigan block, it extends from the north boundary of the map-area south to South Ghost River, and beyond this to Bow River at Kananaskis with several small patches associated with the Costigan faults in the southern half of the map-area.

Lithology and Thickness

Lithologically, the Pika? is a succession of several alternating bands of resistant, dark grey limestones with dolomitic mottling and recessive argillaceous, nodular limestones. Thin limestone conglomerate bands are common throughout. Thickness of the formation is about 300 feet throughout the map-area.

Contacts

The lower contact with the Eldon formation is taken at the lowest occurrence of argillaceous, recessive limestones above massive weathering thin bedded dolomitic limestones of typical Eldon lithology. The contact with the overlying Ghost River formation was not observed.

Age

Identifiable fossils were not obtained from the Pika?

formation within the map-area, but were collected from lithologically and stratigraphically similar beds near Kananaskis. Balk has identified this collection (60F47) as containing the genera Parehmania and Rowia and comments that this collection appears to represent a faunule high in the Bathyuriscus Elrathina zone (c.f. p. 25).

This is in essential agreement with determinations by Wilson and Resser (in Beach, 1943, p. 10) of Ehmania from the Kananaskis section, and determinations by Deiss (in McKinnon, 1942, p. 43) of the trilobite genera Coelaspis, Ehmania, Ehmaniella, Elrathina and Thompsonaspis for the same fauna. According to McKinnon, Deiss refers these fossils to three zones, all of which are found in the Stephen formation of the type area.

North and Henderson (1954, p. 54) pointed out that fossils found at Kananaskis represent the Stephen formation, and consider the cliff-forming limestones below to be correlatives of the Cathedral. In 1956, deWit described this section and correlated the fossiliferous beds with the Pika and the underlying dolomitic limestones with the Eldon formation. It would thus appear that in the Bow River - Ghost River area, the combined Stephen, Eldon and Pika? formations, with a total thickness of 1250 feet, represent only two Middle Cambrian trilobite zones and are together correlative with only the Stephen formation (average thickness 400 feet) of the Field area. Several explanations for this apparent discrepancy are possible:

(1) The Pika? formation in the Ghost River area is correlative with beds referred to the Pika at Kananaskis by deWit.

(a) The beds at Kananaskis are Pika and the fossils indicate that the Bathyuriscus - Elrathina zone encompasses the Eldon and Pika formations, as well as the upper Stephen.

(b) The beds at Kananaskis are Stephen as suggested by the fossils, and the combined Stephen, Eldon, and Pika? formations in the Ghost River area are all correlatives of the type Stephen. This would require pronounced thickening of the Stephen formation eastward between Field and the Ghost River area, a trend not reflected in older Cambrian units.

(2) The Pika? formation in the Ghost River is not a correlative of the Pika at Kananaskis, and the Pika at the latter locality is Stephen, as suggested by the fossils. This would be in keeping with all fossil determinations from Kananaskis but would require the disappearance of the Eldon and Pika? formations between South Ghost and Bow Rivers, a trend not supported by present mapping.

The writer considers that interpretation 1 (a) provides the most reasonable explanation for observed relationships; that is, the *Bathyuriscus* - *Elrathina* zone has a greater vertical range than previously recognized and that the strata in doubt are correlatives of the Pika formation of both the Field area and the Kananaskis section as described by deWit. Two other lines of evidence also support this conclusion. In 1916, Allan mentioned the fact that older Cambrian strata were present in the Ghost River area than could be observed on Bow River, and that these older beds were absent because of the action of the (McConnell) thrust. Mapping in the Ghost River area supports this view. Raasch and Campau (1957) considered that the Pika formation includes the *Thompsonaspis* zone, including the genera *Ehmania*, *Rowia*? *Glyphaspis*, *Clappaspis* and *Kootenia*. If their correlation is correct, the terminology used in the Ghost River area becomes quite reasonable.

Correlation

These beds are then tentatively correlated with the Pika formation of the Field area on the basis of stratigraphic position above the Eldon and are included in the Middle Cambrian because of lithologic similarity to dolomitic limestones of the underlying Eldon formation.

Raasch and Campau (1957) have identified the Pika formation in California Standard Parkland No. 4-12 on the basis of the occurrence, near the top of the Cambrian section as encountered in the well, of the Thompsonaspis fauna and vanHees (1959) has extrapolated this unit over much of central Alberta. The type locality of the Pika formation on Castle Mountain (Mt. Eisenhower) contains an undescribed fauna near the base of the formation, (Deiss, 1939). Near Kananaskis, deWit (1956) has referred beds beneath the Ghost River formation to the Pika formation. This section was examined and found to be lithologically similar to beds referred to the Pika? in the Ghost River area and overlies massive weathering dolomitic limestones that are seemingly identical with those of the Eldon formation in the map-area.

Depositional History of the Cambrian Rocks

Cambrian strata of the Ghost River area were deposited in relatively shallow water on the craton of western Canada.

Alternating sandstones and shales of the Lower Cathedral formation suggest weakly unstable conditions during which well sorted sands and finer material were introduced into the depositional basin from a low-lying land area to the east. Relatively clean sandstones in the lowermost exposed beds of this formation give way

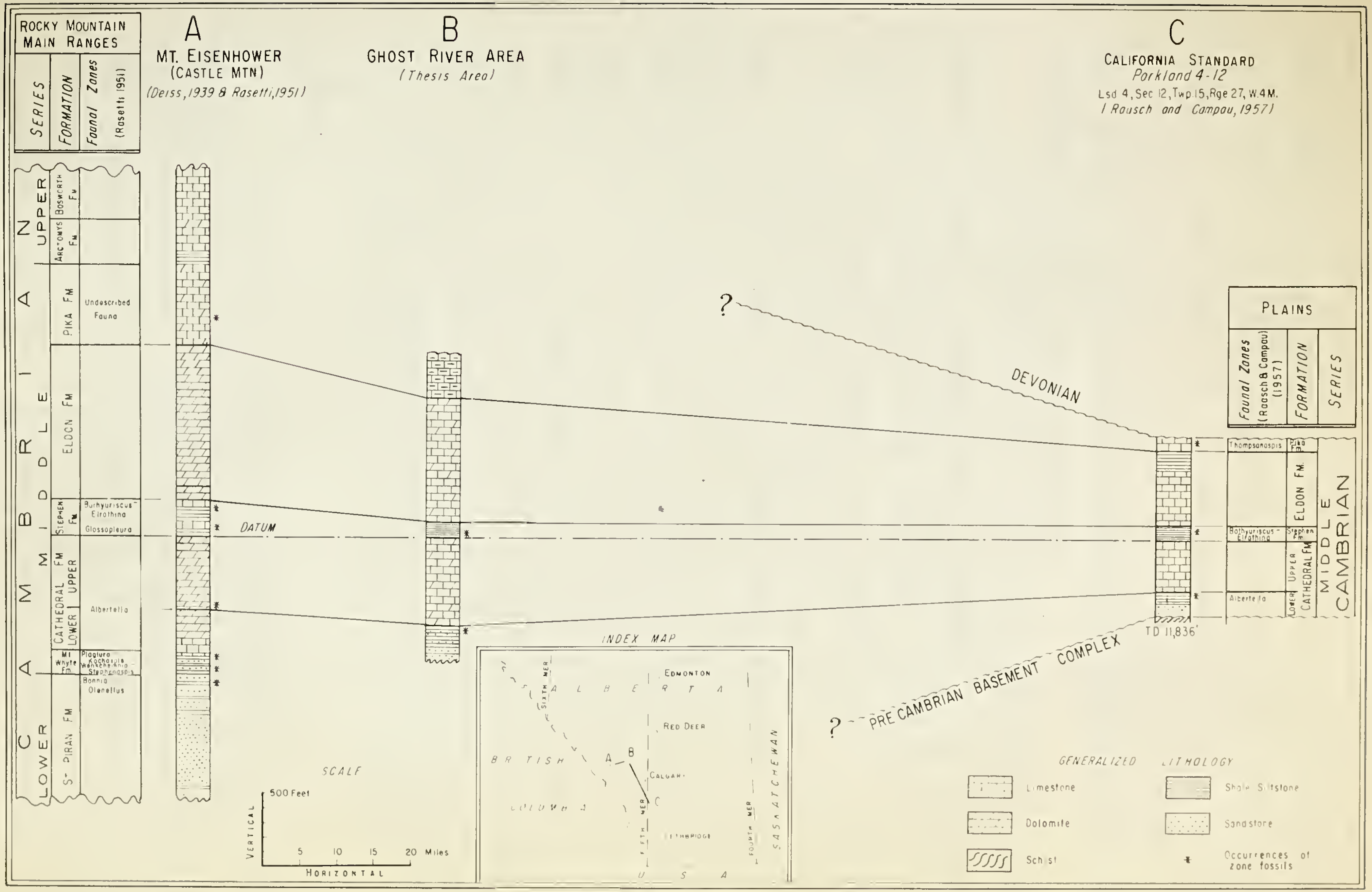


FIGURE 3

CORRELATION OF CAMBRIAN FORMATIONS IN THE GHOST RIVER AREA WITH MT. EISENHOWER AND CALIFORNIA STANDARD PARKLAND 4-12.

upwards to more argillaceous sandstone and greater quantities of shale, and in the uppermost beds of the Lower Cathedral sandstones are replaced by fragmental, coquinoid and conglomeratic limestones alternating with shale. The transition through the thin limestones at the top of the Lower Cathedral to massive limestones of the Upper Cathedral suggests gradual deepening of the depositional basin and greater distance from the shoreline.

Much of Middle Cambrian time was characterized by relatively stable conditions as evidenced by the uniformity of the limestones of the Upper Cathedral and Eldon formations. The presence of pellets, rare trilobite fragments and possibly oolites in these beds is indicative of relatively shallow water in a slowly subsiding basin. Influx of shale into the depositional area that occurred during Stephen time may reflect a period of relative instability of the craton, as the shales of the Stephen are associated with high energy deposits in the form of coarse trilobite coquinas, oolitic limestones, and one conglomerate bed. From bottom to top, the Stephen formation shows a gradual change from limestone of the underlying Upper Cathedral through argillaceous limestone to shale in the middle of the unit, then through argillaceous and thin-bedded limestones into the overlying Eldon limestones as more stable conditions returned.

Shallowing of the sea is again represented by the transition upwards from poorly bedded limestones of the Eldon formation to argillaceous limestone, conglomerate and coquina of the overlying Pika? formation and this shallowing reached its culmination in the siltstones and dolomites of the basal Upper Cambrian Arctomys formation outside the map-area. Van Hees (1959, p. 83) has divided

Middle Cambrian beds of southern Alberta and British Columbia into four broad facies as follows:

(1) Coarse Basal Clastic Belt, northeast of the 50 percent (sand) isolith.

(2) Glauconitic Silt-Shale Belt, between the 50 percent (sand) isolith and (the) eastern margin of carbonates...

(3) Submerging Shelf Carbonate Belt...

(4) Western Deeper Water Shale Belt...

The Ghost River map-area is in the submerging shelf carbonate belt, which extends eastward to central Alberta and is represented by the standard Middle Cambrian facies of the Field area. West of Field the great Middle Cambrian carbonate formations change laterally to the Chancellor shale and its equivalents. To the east, the glauconitic silt-shale belt interfingers with the carbonate facies and eventually gives way, in Saskatchewan, to coarse basal clastics.

The diachronic basal sandstone of the transgressing Cambrian sea, according to van Hees, ranges in age from the <u>Albertella</u> zone beneath the western Alberta plains to the <u>Glossopleura</u> zone in eastern Alberta, and eventually to the top of the Middle Cambrian (Pika Formation) in Saskatchewan. It is quite probable that to the west, the Lower Cambrian St. Piran formation is the lithologic correlative of the basal sand of the Plains region. Lower Cathedral carbonates of the Field area are coeval with a sandstone-shale-limestone sequence in the map-area that is lithologically similar to the uppermost St. Piran and Mt. Whyte formations to the west and seemingly similar to the basal Middle Cambrian as encountered in wells in western Alberta. It is therefore concluded that the Lower

Cathedral formation of the Ghost River area represents the basal diachronic sandstone and overlying transition zone of van Hees.

Ghost River Formation

The Ghost River formation was traced from its type section on the north flank of Phantom Crag over all of the map-area and invariably occurs between the Middle Cambrian Pika? and Upper Devonian Fairholme.

Distribution

The Ghost River formation forms a continuous outcrop band beneath Fairholme dolomites in the Costigan block and outcrops widely as a talus covered bench near the ridge tops in the Orient block. Although some lateral variation occurs, the formation maintains a thickness of close to 350 feet throughout the map-area.

General Description

From a distance the formation appears as a yellowish weathering recessive band between dark grey Fairholme dolomites and grey weathering limestones of the Pika? formation. It is generally extensively covered due to the non-resistant nature of some of the beds. In the type section the formation consists of three recessive and two resistant units. The upper and lower recessive portions are normally covered and may include beds belonging to the adjacent formations. In the northwestern part of the area, the upper two recessive units become more resistant and result in a two-fold division into an upper resistant unit and a lower recessive unit.

The type section of the Ghost River formation was measured between elevations of 6200 and 6500 feet. In descending order, this is:

FAIRHOLME GROUP

327+ DOLOMITE - dark grey weathering, dark grey, fine to medium crystalline, indistinctly bedded, vuggy, fetid.

224-327 COVERED INTERVAL

GHOST RIVER FORMATION

219-224 **DOLOMITE - weathers greyish orange (10YR7/4), light olive grey (5Y6/1), medium to coarsely crystalline in beds 1/2 inch to 1 inch thick. Contains pebbles of greyish green (10GY5/2), cryptocrystalline dolomite up to 2 mm. by 100 mm. in size in certain zones. Quartz and feldspar of coarse silt to very fine sand grade constitute 5 percent to 15 percent of the rock and many of the grains of both minerals have overgrowths. Occasional beds of dolomite conglomerate are present in this unit.

216-219 COVERED INTERVAL

164-216 **DOLOMITE AND SILTSTONE - weathers greyish orange pink (5YR7/2), to moderate yellowish brown (10YR5/4), medium grey (N5) to medium light grey (N6), finely laminated and cross-bedded in beds 2 feet to 5 feet thick with 3 inch to 6 inch thick bands of red and green argillaceous dolomite in 1/4 inch thick beds. These latter bands thin upwards and are absent at the top of the unit. The dolomites are fine to medium crystalline and contain 12 percent to 18 percent quartz and feldspar in the coarse silt and

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* Description supplemented by binocular microscope examination.

** Description supplemented by thin section examination.

very fine sand grades. Many of the grains have overgrowths. Siltstones contain up to 20 percent dolomite and grade with finer lamination to silty dolomite.

148-164 **DOLOMITE - weathers pale yellowish brown (10YR6/2), greyish red (5R4/2), finely banded with laminae 1/2 mm. to 7 mm. thick, very finely crystalline, with rare quartz and limonite. Unit contains several 2 inch thick beds of dolomite conglomerate with rounded, tabular pebbles up to 400 mm. in length. Pebbles are very finely crystalline dolomite with pellets and coarse silt-size quartz. Matrix is coarsely crystalline dolomite.

137-148 DOLOMITE - argillaceous and silty, mottled red and green, in 2 foot thick bands of 1/4 inch thick beds; alternating with 1 to 2 foot bands of 1 to 2 inch thick beds.

124-137 **DOLOMITE - weathers greyish orange (10YR7/4) to light brownish grey (5YR6/1), greyish red (5R4/2), to greyish green (10GY5/2); finely crystalline to very finely crystalline, argillaceous, silty, with cross laminae 0.5 mm. to 4 mm. thick, in beds 1/2 inch to 1 foot thick. Rare very fine quartz sand and limonite. Very light grey (N8) oolitic, dolomitic chert occurs in 6 inch irregular beds between 127 and 132 feet.

107-124 **DOLOMITE - weathers yellowish grey (5Y8/1) to greyish orange (10YR7/4), pale red (5R6/2) to light brownish grey (5YR6/1), in beds 3 feet to 4 feet thick, medium crystalline, with pebbles up to 3 mm. in length and pellets of very finely crystalline dolomite, which occur in both

pebbles and matrix. Some laminae are disturbed; rare quartz of coarse silt grade with overgrowths.

94-107 **DOLOMITE - weathers moderate yellowish brown (10YR5/4), medium light grey (N6), with elliptical to spherical pellets 0.1 mm. to 0.2 mm. of very finely crystalline dolomite forming 25 percent of the rock; in a matrix of finely crystalline dolomite that contains rare coarse silt grade quartz; indistinct 2 inch to 1 foot thick beds.

78-94 **DOLOMITE - weathers pale yellowish brown (10YR6/2), medium light grey (N6), finely crystalline, silty; with 1 mm. to 10 mm. thick irregular cross laminae at intervals of 2 mm. to 400 mm. of dolomite with 30 percent coarse silt grade feldspar and quartz.

59-78 COVERED INTERVAL

50-59 *DOLOMITE - weathers pale yellowish brown (10YR6/2), pale yellowish brown (10YR6/2), in beds 1/4 inch to 1/2 inch thick, very finely crystalline, with 2 mm. to 5 mm. thick laminae and dark brown segregations.

32-50 **DOLOMITE - weathers moderate yellowish brown (10YR5/4), medium light grey (N6), medium crystalline with medium silt size feldspar and quartz up to 20 percent of the rock; in 1/4 inch to 1 inch thick beds in 6 inch thick units; interbedded with 1 foot to 3 foot bands of argillaceous pale red (5R6/2) dolomite; some pellet dolomite and finely crystalline dolomite with pyrite and up to 20 percent coarse silt-size feldspar with overgrowths.

10-32 COVERED INTERVAL

0-10 **DOLOMITE - weathers medium grey (N5) to yellowish grey (5Y8/1), dark yellowish brown (10YR4/2), to medium grey (N5), finely crystalline, argillaceous, with elongate sub-rounded pebbles 1 mm. to 4 mm. thick of finely crystalline greyish brown (5YR3/2), weathering dolomite. Pebbles are inclined at angles up to 30 degrees to the bedding.

COVERED INTERVAL (35 feet)

PIKA? FORMATION

LIMESTONE - thick bedded, dolomitic.

Age and Correlation

The first description of this unit was made by McConnell (1887, p.20D) in Devils Gap where he assigned "A light-yellowish siliceous band varying in thickness from 100 to 400 feet..." to the base of the Intermediate (Fairholme) limestone of Devonian age. Since McConnell's time the Ghost River, occurring as it does between strata of Upper Devonian and Cambrian age, has had a long and controversial history with some workers placing the formation in one System or another and others recently assigning a multiple age to it. The recent discovery of Devonian plants and fish in this formation south of South Ghost River by Gussow (1960, p. 159) and Patterson and Storey (1960), has solved the problem of its age.

Many of the difficulties arising from past attempts to date the Ghost River formation are undoubtedly due to the tendency to correlate this formation for considerable distances when its position adjacent to a major unconformity should suggest that rapid lateral changes might be expected.

In the Bow River area, Clark (1954) mapped and described sections of the Ghost River formation (150 to 170 feet thick) as being of probable Devonian age. This age was suggested mostly on the basis of an angular unconformity at the base of this unit.

DeWit (1956) examined the Cambrian-Devonian section at Kananaskis as well as other sections across the sub-Devonian unconformity in the Front Ranges west of this locality. On the basis of lithologic correlations with the more complete Cambrian sections exposed west of Kananaskis, he divided this section in descending order into the following units:

Upper Devonian Fairholme Group	
Basal Devonian unit	6'
Upper Cambrian Arctomys Formation	25'
Middle Cambrian Pika Formation	289'
Middle Cambrian Eldon Formation	76'+

DeWit (ibid) referred the Basal Devonian unit and the Arctomys formation to the Ghost River formation.

In 1960 Gussow (p. 159) reported fish and plant remains at "End" Mountain south of South Ghost River, in the basal beds of the formation. It is assumed that he used the term "Ghost River" in the same sense that Clark did. This discovery provides the first definite evidence for a Devonian age for this unit.

Although the Devonian age has been established, the problem of correlation with the subsurface of Alberta remains. Several workers have suggested a possible correlation of the Ghost River formation with the Middle Devonian Elk Point group of central Alberta primarily on a lithological basis. Indirect evidence is presented here to support a possible correlation of the Ghost River formation with the Beaverhill Lake group of the Alberta subsurface (Figure 4).

The arguments are proposed mainly on the basis of regional distribution of the Elk Point and Beaverhill Lake groups.

(1) Belyea (1959, Figures 1 and 2) illustrated maps and cross-sections of the Elk Point group which show a regional westerly thinning from 1800 feet northeast of Edmonton, to less than 100 near Calgary. She stated that the lower units of the group are restricted to the central part of the Elk Point Basin and that successivly higher units are areally more extensive, the uppermost being the most widespread. She concluded that a relatively positive area existed in southwestern Alberta during all of Elk Point time. If her isopach values are extrapolated beyond the 100 foot contour (east of Calgary) a zero thickness contour should occur somewhere near the eastern edge of the Foothills belt, well to the east of the Ghost River area.

(2) Belyea (1957, p. 7) earlier described the distribution and thickness of the Upper Devonian Beaverhill Lake group, which thins southwesterly from over 700 feet in the type section (Anglo Canadian Beaverhill Lake No. 2 well, Lsd. 11, Sec. 11, Twp. 50, Rge. 17, W4 Meridian) to less than 200 feet at Moose Mountain west of Calgary. Extrapolation of this rate of thinning suggests that the Beaverhill Lake group should terminate somewhere within the easternmost Front Ranges west of Calgary. She also demonstrated that the group thins by onlap to the west, the uppermost unit (Bh6) being the most widespread. Dolomite is characteristically found at the base of the Beaverhill and the proportion of dolomite to limestone increases as the group thins. It follows that individual units become dolomitic as they approach their shorelines.

Extrapolation of Belyea's data into the Ghost River area suggests firstly that the Beaverhill Lake group would be thin (e.g. 200 feet) and secondly that it would be largely dolomite. Certainly, on the basis of the above isopach maps, there would appear to be a greater probability of younger strata than Elk Point in the map-area. The thickness of Beaverhill Lake equivalents in the Ghost River area would be somewhat greater than Belyea's map would indicate, since she has excluded Ghost River equivalents in the Moose Mountain area.

(3) According to deWit (1956, p. 100), the Ghost River formation is restricted to the easternmost Front Ranges. Further west the Fairholme group rests directly on Cambrian or Ordovician beds. No data is available regarding the distribution of the Ghost River formation to the east of the Front Ranges. From the above, it may be concluded that the formation thickens easterly from a zero edge in the Front Ranges to approximately 300 feet at its easternmost exposures. This direction of thickening is consistent with that observed in the Beaverhill Lake and Elk Point groups and is quantitatively similar to that in the former.

(4) Fossil collections (see page 56) made at three localities in the map-area from beds a short distance above the Ghost River formation contain faunas typically developed in the Flume formation of the Rocky Mountain Front Ranges, and in the Cooking Lake formation in the subsurface of central Alberta (Warren and Stelck, 1956); Belyea and McLaren, 1956). The palaeontological evidence suggests that beds overlying the Ghost River formation in the map-area are correlatives of the subsurface Cooking Lake formation. These faunas are widespread near the base of the Fairholme group throughout the

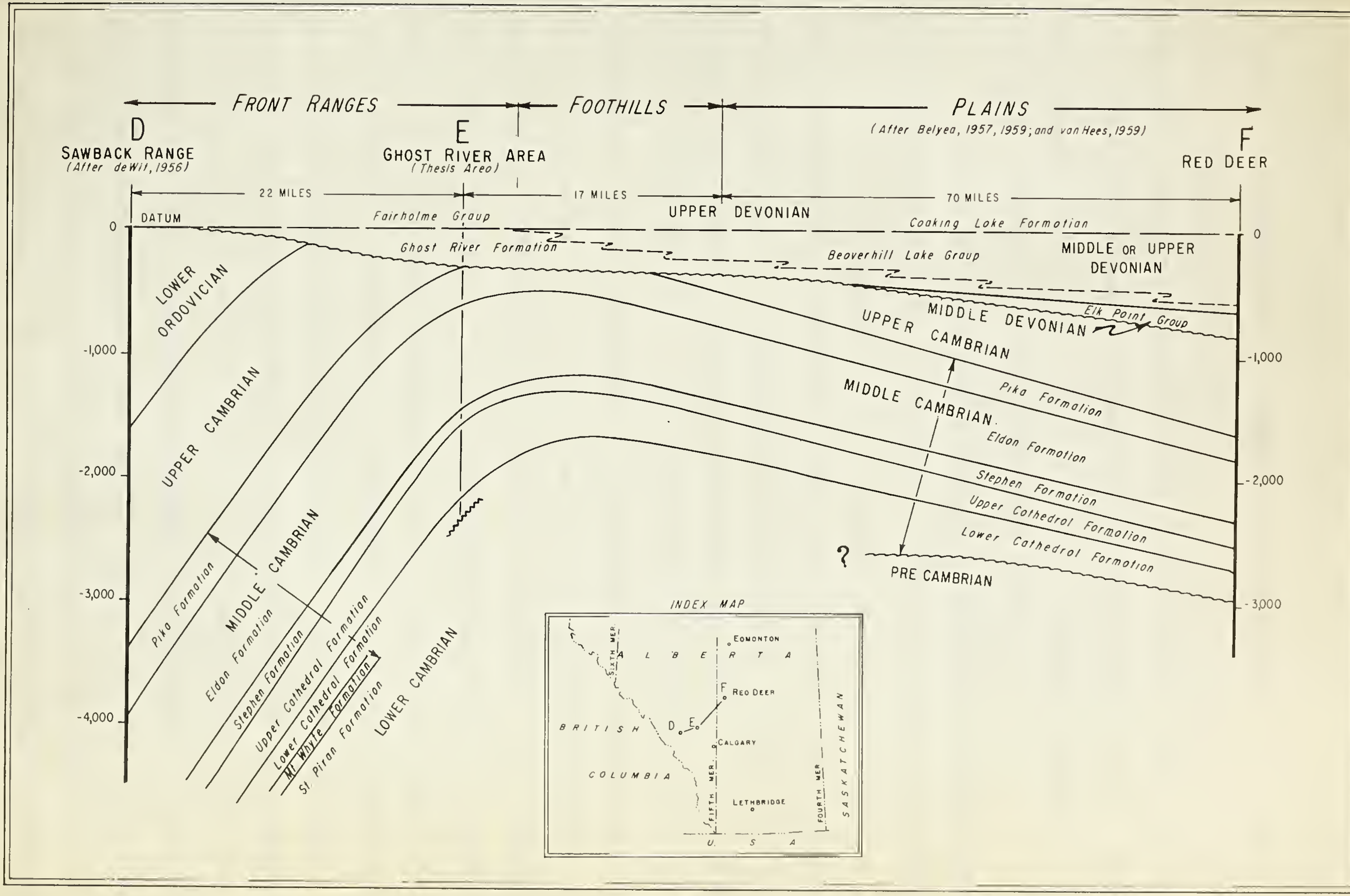


FIGURE 4

DIAGRAMMATIC CROSS-SECTION SHOWING REGIONAL RELATIONSHIPS OF CAMBRIAN AND DEVONIAN STRATA WITH REFERENCE TO THE GHOST RIVER AREA DURING

Front Ranges. On stratigraphic position, beds below this faunal horizon would be expected to be correlatives of the Beaverhill Lake group. If the Ghost River formation was equivalent to the Elk Point group, a significant hiatus must exist between this and the basal Fairholme. Evidence of such a break is not present in the subsurface of central Alberta and the overlapping of the younger strata beyond the present limits of the Elk Point is a convincing argument for a Beaverhill Lake age for the Ghost River formation.

Since the Ghost River formation represents the basal beds of the Devonian System, it is perhaps easier to explain the apparent discrepancies in conclusions regarding the age of the formation within the Bow River-Ghost River area. Most authors have remarked on the difficulty of recognizing the unconformity because of lithological similarity of beds above and below the hiatus. At the type section strata adjacent to the unconformity are covered but the lithological change is marked. It is reasonable to assume that a certain amount of relief existed on the erosion surface and that this would be reflected in variations in thickness of the overlying Ghost River formation. It is also evident that in much of the Front Range area, lithologic correlatives of the formation are entirely lacking, and the conclusion is unavoidable that these deposits wedge out a short distance west of the map-area. The realization that rapid westerly thinning occurs and that local variations in thickness would be expected because of relief on the unconformity makes the reported variable lithology and thickness of this unit more reasonable. Thus it is quite possible that deWit's (1956) reported thicknesses of 6, 30 and 61 feet for the Basal Devonian Unit in the Bow River area are not incompatible with Clark's (1954) (150-170 feet) or with the type section (224+ feet).

Depositional History of the Ghost River Formation

Clark (1954) suggested that the Ghost River formation represented deposits of a "playa deposit laid down without the aid of strong wave or stream action, the basal bed being in the nature of carbonate mud produced by partial solution of the underlying limestone rather than the usual mechanically derived basal beds of unconformable formations." The present study supports this interpretation to some extent. Many of the dolomites are very finely crystalline, finely laminated rocks that would be normally classified as primary dolomites and suggest relatively low energy conditions in the depositional basin. Other lithologic types are indicative of more agitated water. The relatively common occurrence of pellets and conglomerates in the formation suggest turbulent shallow water, as do the rare oolitic cherts observed in the type section.

Dolomites that are not "primary" are probably relatively early and precede the growth of authigenic feldspar and quartz. Formation of chert may have been contemporaneous with dolomitization of the original pellet limestones.

Detrital material is mainly of coarse silt grade and possibly originated in the Upper Cambrian Arctomys or Ottertail formations, both of which subcrop at the pre-Devonian unconformity a short distance west of the map-area.

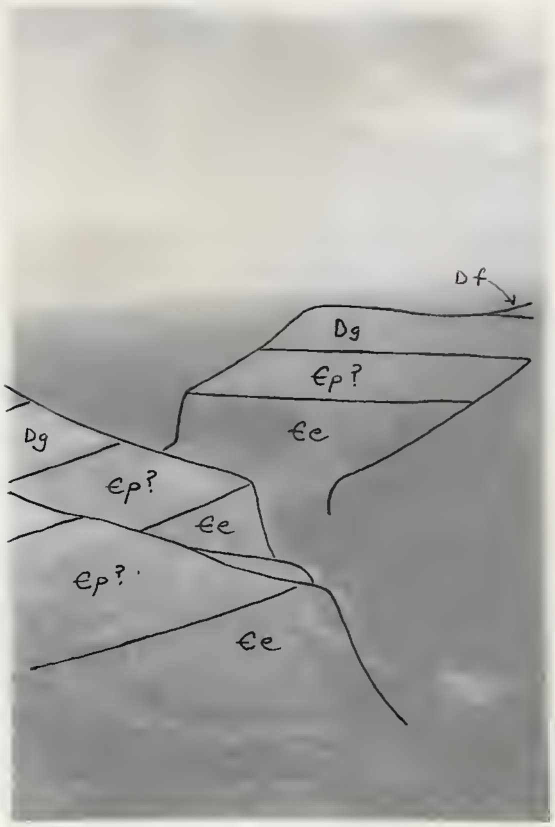
The alternation of thick units of argillaceous dolomite and silty dolomite in the Ghost River formation suggests mild instability of the depositional basin. If this formation is coeval with the Beaverhill Lake group, these alternations may eventually permit of correlation with similar cycles in the subsurface. Dolomites of the Ghost River formation represent shallow water

Description of Plates

Plate 3

A - Stratigraphic section as exposed in Orient block of McConnell thrust sheet (looking east down first south tributary of Waiparous Creek).

B - Orient and Costigan blocks of the McConnell thrust sheet (looking south across Burnt Timber Creek).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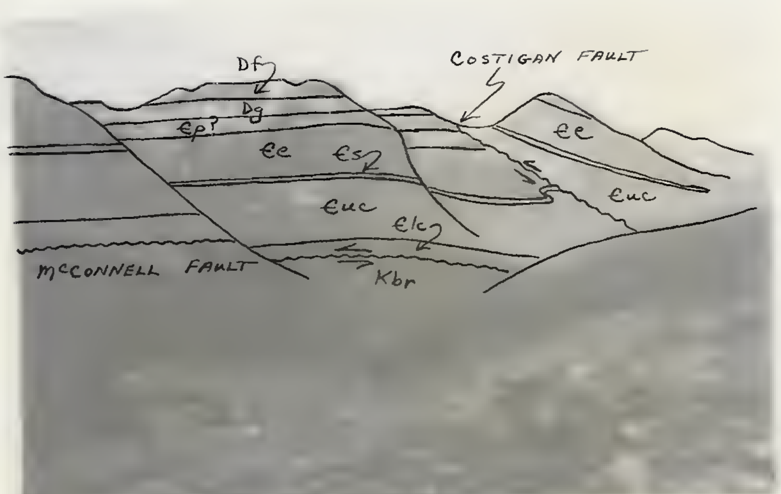
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Description of Plates

Plate 3

A - Stratigraphic section as exposed in Orient block of McConnell thrust sheet (looking east down first south tributary of [illegible] Creek).

B - Orient and Costigan blocks of the McConnell thrust sheet (looking south across Burnt Timber Creek).

deposits of the transgressing Devonian sea. Minor detrital material originated from a low-lying land area to the west which was submerged by the beginning of Fairholme deposition.

Fairholme Group

Porous, fossiliferous dolomites of the Upper Devonian Fairholme group outcrop extensively in the Ghost River area but were not examined in any detail. The group is well known in the Front Ranges and summaries of the stratigraphy of these rocks are included in the bibliography.

Distribution

The main outcrop belt of this group occurs in the Costigan block and extends from the northern boundary of the map-area, south to Bow River, which it crosses at Kananaskis. In the Orient block, the Fairholme group forms the upper slopes of Orient Point. Almost complete sections are exposed on Phantom Crag and on Devils Head beneath the Costigan fault. Throughout the remainder of the Orient block the basal part of the group is widely exposed on the interstream divides as erosional remnants of various sizes.

Lithology and Thickness

The uppermost portion of the Fairholme group was not examined in the map-area. Beds high in the group on Devils Head consist of massive, crudely bedded light grey dolomite, with occasional interbeds of more thinly bedded, darker dolomite. These beds represent part of the Southesk formation (McLaren, 1955). Lower in the section, vuggy, stromatolotic, dark grey dolomite with white calcite and chert near the base are representative of the Cairn formation (ibid). Stratigraphic sections of this group have been described

in the Costigan block at Lake Minnewanka (deWit and McLaren, 1950, pp. 58-60) where it is 1184 feet thick and at Kananaskis (McLaren, 1955, Figure 1) where the thickness is 1116 feet. The Fairholme is calculated to average 1050 feet thick in the Ghost River area.

Contacts

The lower contact is usually covered but was examined, on a south flowing tributary of Ghost River west of the Costigan fault where stromatolitic light grey weathering Fairholme dolomite outcrops within a few inches of medium bedded, hard resistant dolomites of the underlying formation. The two units appear conformable in this exposure.

The upper contact with the Alexo formation was not examined in the area but is described (McLaren, ibid) as being sharp and conformable.

Age

Fossils were collected from three localities in dark grey, calcareous shale interbedded with stromatolitic dolomite near the base of the Fairholme group and these collections have been identified by Dr. P.S. Warren as follows:

Collection 60F236 - 1 mile north of Castle Peak, elevation 8500 feet; approximately 200 feet above Ghost River formation.

Nudirostra athabascensis (Kindle)

Collection 60F551 - 2 miles west of the head of Burnt Timber Creek, elevation 6850 feet; 180 feet above the nearest exposures of the Ghost River formation.

Eleutherokomma jasperensis (Warren)

Productella sp.

Schizophoria sp.

Collection 6007A - Ridge between Burnt Timber and Waiparous Creeks, elevation 8400 feet; 20 feet above the top of the Ghost River formation.

Eleutherokomma jasperensis (Warren)

Dr. Warren states that this is the normal fauna of the Flume formation. It belongs in the *Eleutherokomma leducensis* fauna of Warren and Stelck (1956, p. 5) or the *Nudirostra athabascensis* zone of McLaren (1954, p. 160).

The *Eleutherokomma leducensis* fauna is widespread in the Front Ranges of western Alberta near the base of the Fairholme group. It occurs in the Flume formation of the clastic sequence and the Cairn formation of the carbonate sequence. In the subsurface of central Alberta, this fauna is well developed in the Cooking Lake formation (Belyea and McLaren, 1956, p. 89; Warren and Stelck, 1956, pl. XIV).

Alexo Formation

A thin yellowish weathering, thinly bedded recessive unit that occurs throughout the map-area beneath cliff-forming limestones of the Palliser formation is referred to the Alexo formation of Upper Devonian age. This formation provides an easily recognizable horizon for mapping purposes both on the ground and on aerial photographs.

The Alexo formation forms a continuous outcrop band in the Costigan block through the map-area from near the head of Burnt Timber Creek to South Ghost River and beyond this to Bow River. The only occurrence of this formation in the Orient block is a narrow band encircling the peak of Orient Point. A small patch may also be present at the summit of Phantom Crag.

North of the Ghost River area the outcrop belt of the Alexo formation is offset to the west by a transverse fault and continues north around the eastern slopes of Mount Oliver at the head of North Burnt Timber Creek. Where examined, outcrops were found to consist of medium to thick bedded, medium crystalline, porous light grey dolomite. This lithology is not considered typical of the formation: the outcrop being due to its greater erosional resistance compared to the more thinly bedded portions of the formation. The formation has a calculated thickness of about 150 feet. This agrees closely with the description of 166½ feet of laminated dolomite and argillaceous siltstone with some silty dolomite on the north side of Lake Minnewanka in the Costigan block (deWit and McLaren, 1950, pp. 57-58).

Palliser Formation

The Palliser formation outcrops in the Ghost River area as a cliff of dark grey dolomitic limestone above the gentle slopes of the Alexo formation. It is readily recognized in the field and on aerial photographs as a thick, massive, resistant unit with more thinly bedded strata at the top, overlain by the black Exshaw shale.

The outcrop belt of the Palliser formation in the Costigan block lies west of, and parallel to, that of the underlying Alexo formation, and extends from Bow River at least as far north as Mount Oliver. With the exception of the top of Orient Point, the Palliser formation has been removed by erosion from the Orient block.

Palliser limestones were not examined in the map-area. At Lake Minnewanka, deWit and McLaren (1950, pp. 55-57) and McLaren (1955, p. 23) describe the formation as consisting of a lower Morro member, 723 feet thick, of dark grey, finely crystalline, variably dolomitized massive limestone underlain by massive grey dolomite,

and an upper Costigan member, 115 feet thick, of thinly bedded, dark grey, fossiliferous limestone with occasional beds of grey calcareous dolomite. In the Ghost River area the thickness of the Palliser formation is calculated to average 820 feet.

Banff Formation

The Banff formation is an easily recognizable recessive unit between cliff forming limestones of the Palliser formation and Rundle group. Few exposures were examined and its distribution in the map-area was established mainly from aerial photographs.

The Banff formation outcrops only in the Costigan block west of the outcrop belt of the Palliser formation. Miller (1959) and Clark (1954, pl.I) show a thin band of this unit above the Exshaw fault from Lake Minnewanka south. The base is easily recognizable, where thin bedded limestones of the Costigan member are overlain abruptly by black shale of the Exshaw formation, included here with the Banff for mapping purposes. Overlying the thin Exshaw shale is a 10 to 15 foot thick bed of calcareous siltstone which weathers a distinctive orange color and which in turn is overlain by dark grey calcareous shale of the lower Banff formation. The foregoing thin units are readily recognizable in the field and on aerial photographs. Higher in the Banff formation, limestone becomes more prominent and the contact with the overlying Rundle group is difficult to place (see Nelson and Rudy, 1959). Massive light grey weathering crinoidal limestone beds near the Banff-Rundle contact tend to be lenticular along the strike and difficulty is experienced in tracing a constant horizon for any distance on aerial photographs. A horizon was chosen at the base of a prominent massive limestone and this was carried the length of the outcrop belt. The calculated thickness for the Banff

using this horizon is 870 feet throughout the area. This is in fair agreement with other measurements in the same thrust sheet of 1000 feet on Bow River (Clark, 1954, p. 41) and 660 feet on Dormer River (Hunt, 1956, p. 49), the difference probably being due to the use of different horizons to separate the Rundle and Banff.

Rundle Group

Two outcrop belts of the Mississippian Rundle group occur in the Exshaw thrust sheet from South Ghost River to the head of Ghost River at Mount Oliver and in the Costigan block from Bow River to beyond the north edge of the area. Clark (1954, p. 41) subdivides the Rundle into upper and lower units and reports thickness of 600± feet and 1100 to 1300 feet respectively for these two divisions. Hunt (1956, p. 49) gives a thickness for the Rundle group in the McConnell thrust sheet to the north of the map-area of 1467 feet. Calculated thickness of the group in the Ghost River area is 1700 feet.

Rocky Mountain Group

These rocks were not examined in the map-area. They outcrop sparingly below tree line and tend to be talus covered at higher elevations. The more easterly of two outcrop bands of the group is discontinuous and parallels the outcrop of the Rundle in the Costigan block from the north edge of the area to Bow River. The western band is present in the Exshaw thrust sheet from Mount Oliver at the head of Ghost River south as far as Lake Minnewanka.

Clark (1954, p. 43) describes the Rocky Mountain group as "...massive and in places rather poorly bedded grey sandy dolomite, dolomitic and siliceous fine-grained grey sandstone, and cherty dolomitic grey quartzite...", 275 feet thick in the Bow River area. Calculated thickness of these rocks in the map-area is 330 feet.

Spray River Formation

Complete sections of the Triassic Spray River formation were not observed within the Ghost River area. This unit is generally poorly exposed and with the Rocky Mountain group underlies grass or tree covered slopes above cliffs of Rundle limestone.

The more westerly of two outcrop belts follows Ghost River from its headwaters south to Lake Minnewanka as a part of the Exshaw thrust sheet. A discontinuous band occurs immediately beneath the Exshaw fault in the Costigan block and extends through the map-area south to Bow River. A maximum thickness of 800 feet is calculated for the Spray River in the Costigan thrust sheet. The formation is always overlain by the Exshaw fault and it is possible that Jurassic beds may appear locally in patches above the Spray River in this belt. Younger Mesozoic rocks overlie this unit west of the map-area, but since the top of the formation was not established, no thickness was determined. The formation where examined along Ghost River, consists of thin to thick bedded, brown weathering, grey dolomitic siltstone and fine sandstone.

Wapiabi Formation

Two small areas of Wapiabi are present on Burnt Timber Creek and on South Ghost River. The former is the southern continuation of a larger area near Panther River; the latter is isolated and overlain by the McConnell fault.

The upper 500 feet of the formation on Burnt Timber Creek, consists of fissile to blocky, dark grey shales with large ironstone concretions. Hunt (1956, p. 49) reports a total thickness of Wapiabi strata of 2200 feet in the Panther River area. The upper 500 feet of the formation on Burnt Timber Creek, consists of fissile to blocky,

dark grey shales with large ironstone concretions. Towards the top the beds become increasingly sandy and silty and have a green colour. The contact with the overlying Belly River formation is gradational and is placed at the base of a resistant, massive sandstone.

On South Ghost River, the uppermost 200 feet of the Wapiabi formation occur in the overturned west limb of a small syncline beneath the McConnell fault. The transition to sandstones of the Belly River formation is similar to that on Burnt Timber Creek. Marine fossils occurring in concretions about 100 feet below the top of the formation in concretions belong to the genera Inoceramus and Baculites.

Belly River Formation

Sandstones and shales of the Upper Cretaceous Belly River formation outcrop throughout most of the foothills east and north of the McConnell fault. The contact with the underlying Wapiabi formation on Burnt Timber Creek dips southerly beneath the McConnell fault. On South Ghost River the overturned contact occurs below the McConnell thrust. Projections of measured attitudes at these two localities suggest that about 3000 feet of Belly River beds remain beneath the McConnell fault on Burnt Timber Creek and approximately 2000 feet on South Ghost River.

STRUCTURAL GEOLOGY

The greater part of the Ghost River map-area lies above the McConnell thrust fault which at this latitude represents the boundary between the Foothills and Front Ranges sub-provinces of the Rocky Mountains. The central part of the map-area is underlain by the Orient block of the McConnell thrust sheet, the western part by the Costigan block and the Exshaw thrust sheet. The Exshaw thrust sheet and the Costigan block are homoclinal structures similar to many of the typical Front Range thrust sheets, whereas theOrient block forms a gently dipping panel of Palaeozoic strata that has overriden Upper Cretaceous beds of the Foothills belt on the McConnell thrust (Plate 1). North of the Ghost River, the Costigan block is underlain by the Costigan thrust, which south of this river is replaced by a fault zone, herein called the Costigan fault zone, consisting of three or four westerly dipping thrust faults. Along the transverse portion of the Ghost River, the Ghost River tear fault cuts the Costigan block and the western part of the Orient block and offsets the Costigan thrust. The eastern edge of the Orient block contains the Black Rock imbricate belt, but otherwise the structure of this block is relatively simple, consisting of a series of open folds north of the Ghost River and dominated by the End Mountain syncline to the south. Erosion has limited the outcrop area of the Orient block to a rectangular area between South Ghost River and Burnt Timber Creek.

Upper Cretaceous strata of the Foothills belt have been strongly folded beneath the McConnell thrust in the southern part of the map-area and are gently warped along Burnt Timber Creek.

McConnell Fault

The McConnell fault is the largest single structural element of the Ghost River map-area. This fault was originally described by R.G. McConnell (1887, pp. 33D-34D) from exposures on South Ghost and Bow Rivers, and was named by Clark (1954, p. 44) in the Bow River area. The fault has a length in excess of 200 miles, extending from south of Athabasca River near Jasper, southerly to Highwood River, southwest of Calgary. It has been mapped in the following Geological Survey map-areas, which are from north to south: Miette, Mountain Park, George Creek, Nordegg, Cripple Creek, Costigan Coal basin, Morley, Moose Mountain, Dyson Creek, and Mount Head. Mapping from other sources includes Panther River (Hunt, 1956), Banff-Exshaw (Miller, 1959), Bow River (Clark, 1954), and Moose Mountain (Dahlstrom and Henderson, 1959) map-areas.

The presently mapped parts of the fault are separated by an extensive unmapped area between Red Deer and North Saskatchewan Rivers. From the Mount Head map-area stratigraphic throw on the McConnell thrust increases progressively from zero to 17,000 feet in the Ghost River map-area, 70 miles to the north. Most of the change in stratigraphic throw takes place in the hanging wall of the fault as the thrust cuts stratigraphically older beds between the Rocky Mountain and Lower Cathedral formations along strike to the north.

In the Ghost River area, the fault and adjacent beds are generally covered, but its position may be established within a few hundred feet. The actual fault plane was examined near Burnt Timber Creek, where dolomitic limestones of the Lower Cathedral formation overlie slickensided silty shale and coal of the Belly River formation with a virtual absence of small-scale structures (Plate 2C).

The Mountain front north of the map-area is underlain by this fault, which extends south to the head of Burnt Timber Creek, at which point the Costigan thrust branches from the McConnell thrust (Plate 3B). From here the trace of the thrust extends northeasterly along the south side of Burnt Timber Creek for 4 miles (Plate 4A,B), then swings to the southeast to traverse the east slope of "End" and "Sheep Meadow" Mountains and cross Waiparous Creek and the East Flank of Black Rock Mountain from Black Rock Mountain the fault trace trends almost due south along the foot of Orient Point (Plate 4C) as far as South Ghost River. Erosion has caused the trace to extend about 1 mile up the valley of South Ghost River in an irregular manner (Plate 5). South of the map-area,(Clark, 1954, Pl.1) the McConnell thrust has a sinuous trace as far as Bow River.

For much of its length in the Ghost River area, the McConnell thrust underlies beds of the Lower Cathedral formation and with the exception of a small area of Wapiabi strata on South Ghost River, rests on sandstones and shales of the Belly River formation. Beneath "End","Sheep Meadow" and Black Rock Mountains, and apparently in the small klippe north of Burnt Timber Creek, the thrust has cut higher stratigraphically into beds of the Upper Cathedral formation, and on the east flank of Orient Point, Lower Cathedral to Pika? strata are rapidly cut off by the fault, which underlies Eldon limestone on South Ghost River (Plate 4C). South of the map-area beds of the Eldon and Pika? formations occur in the hanging wall of the thrust, which overlies Belly River strata as far south as Bow River.

Except for the exposures on South Ghost River, where the angle h* is relatively high, the fault appears to conform closely in

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* When a thrust fault initially forms in a series of gently dipping sedimentary rocks, the attitude it assumes will be a compromise

attitude to the overlying beds.

Hanging Wall Structures

In many exposures of Cambrian beds in close proximity to the McConnell thrust, the limestones are found to be finely fractured within a few feet of the fault and little affected on a small scale beyond this. Intense folding and thrust faulting frequently occurs, however, for several hundred feet above the thrust or is inferred to have occurred in places where the McConnell fault is not exposed. Many of the larger structures of this type are included in the Black Rock zone of thrust faults and will be discussed below.

Along Burnt Timber Creek little discordance in attitude was noted between beds on either side of the thrust and the hanging wall beds of the Lower Cathedral formation appear essentially unaffected by the underlying fault (Plate 2C). The fault is locally

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between a potential shear plane, and a tendency to follow pre-existent planes of weakness, in this case bedding surfaces. In alternating competent and incompetent strata, the thrust will tend to follow bedding in the incompetent units, and will more closely approach the expected shearing angle in competent beds.

Subsequent to its formation, both the fault and the adjacent strata may, because of other factors, assume a dip that is quite unrelated to the original angle at which the fault transected the bedding. Although this angle is of considerable importance in the interpretation of thrust fault behavior, it is completely ignored in the conventional subdivision of thrust faults into "high-angle" and "low-angle" types solely on the basis of the present attitude of the fault.

Since no adequate terminology for this "initial" or "Original" angle of intersection of the fault and bedding is in common use, it is here proposed, for convenience to alphabetically designate this angle in both the footwall and the hanging wall of a thrust fault. The angle "h" will therefore be used to designate the angle of intersection with the fault of any horizon in the hanging wall. Theoretically, this angle could face in any direction, but characteristically opens in a direction opposed to the direction of movement of the hanging wall of the fault. A similar angle in the footwall is designated as "f" and will normally open in the direction of movement of the hanging wall. The value of these angles will vary upwards from 0 for a bedding plane fault, and prior to movement on the fault, h will be equal to f.

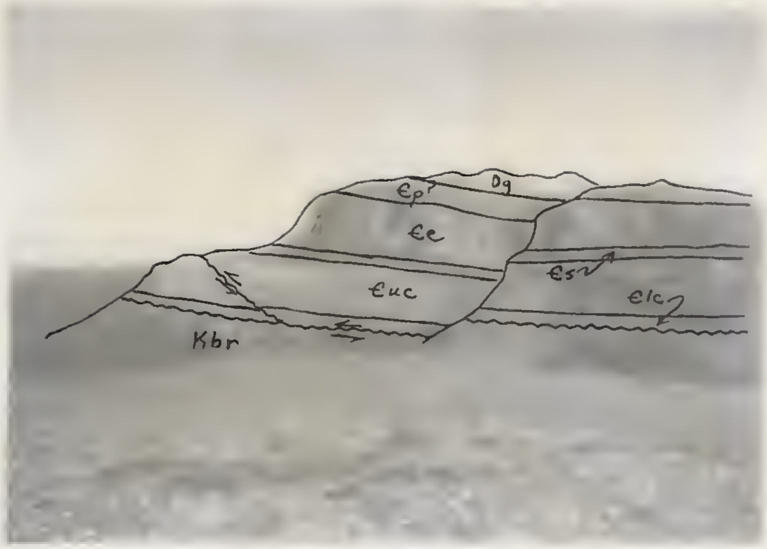
Description of Plates

Plate 4

A - Northern end of Orient block of McConnell thrust sheet (looking east across Burnt Timber Creek).

B - Northern end of Orient block of McConnell thrust sheet (looking south).

C - Orient block of McConnell thrust sheet, east limb of End Mountain syncline (looking west).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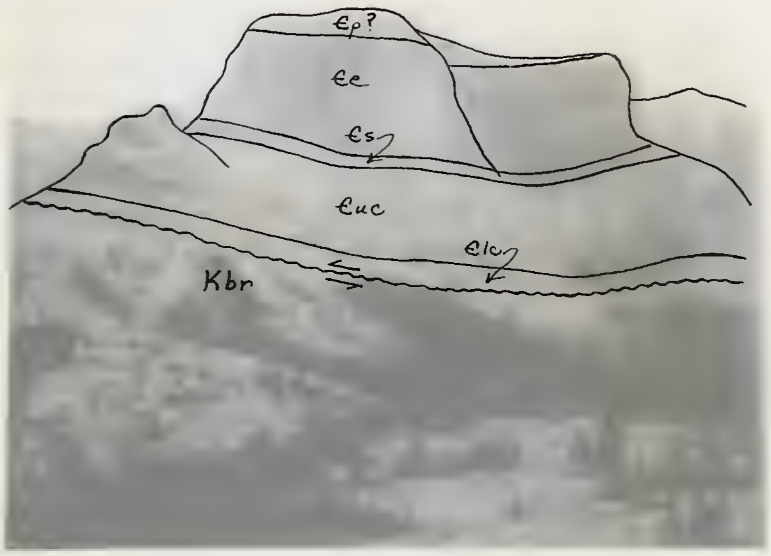
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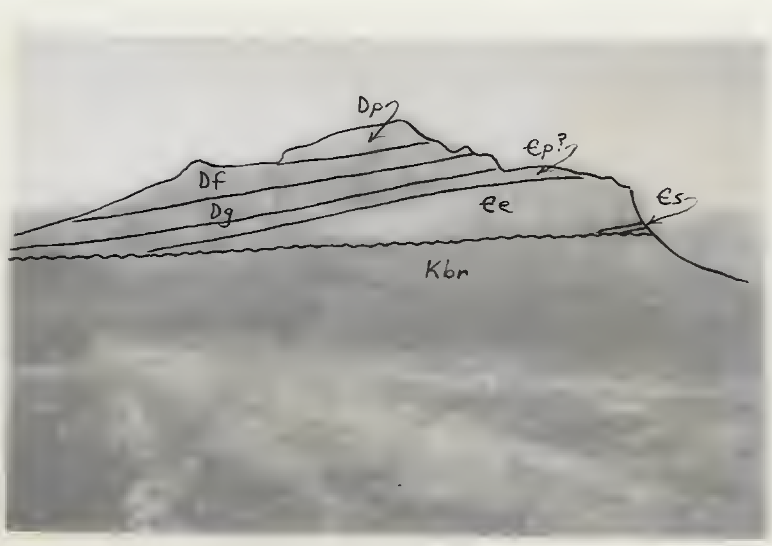
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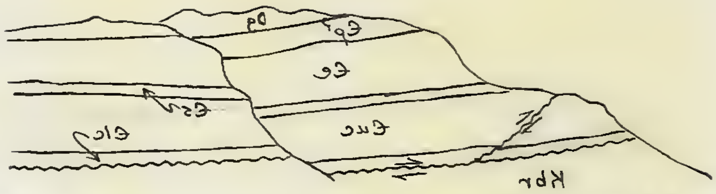
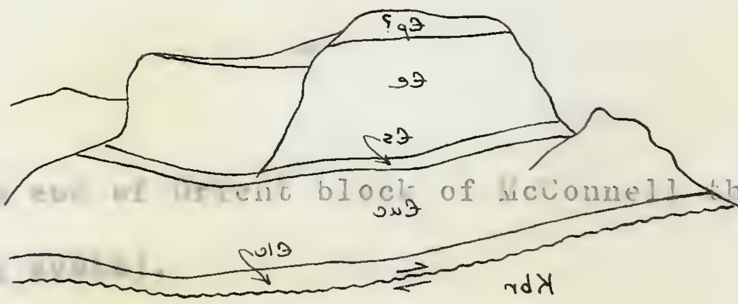
Description of Plates

Plate 4

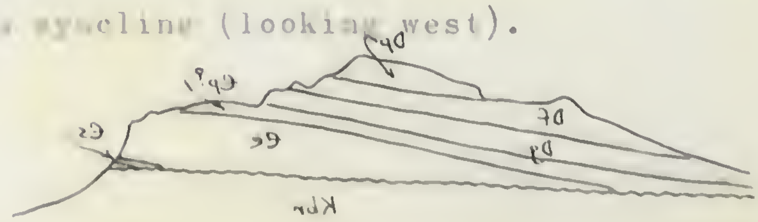


A - Southern end of Orient block of McConnell thrust sheet (looking east across Burnt Timber Creek).



B - Northern end of Orient block of McConnell thrust sheet (looking south).

C - Orient block of McConnell thrust sheet, east limb of End Mountain syncline (looking west).



parallel to bedding in the Cambrian limestones (h = 0). One steeply dipping thrust fault with h and f equal to about 60 degrees cuts Upper and Lower Cathedral beds above the McConnell thrust and dies out in a flexure before rising into the Stephen formation. Dip slip of this fault is estimated to be 50 to 100 feet.

On Waiparous Creek, Lower Cathedral limestones poorly exposed in the stream bed have been folded into an anticline and syncline that strike north 30 degrees west and plunge 20 degrees south. The limbs of these folds have an average maximum dip of 35 degrees and the limestones are heavily veined with calcite. Massive limestones of the Upper Cathedral formation are heavily fractured where exposed above the McConnell fault along the east flanks of "Sheep Meadow" and Black Rock Mountains.

Cambrian limestones exposed above the thrust on the Ghost River are heavily veined with calcite and finely fractured. Immediately above the McConnell fault the beds strike north 80 degrees east and dip 35 degrees north and are cut by a small northwest striking, steeply east dipping fault. For two miles up Ghost River from this locality, all exposures examined were fractured and attitudes were variable. Upper Cathedral, Stephen, Eldon and Lower Cathedral beds, all badly disturbed, are encountered between the outcrop of the thrust and the Ghost River Diversion where Lower Cathedral sandstones are faulted, veined and isoclinally folded. A projection of the known positions of the thrust in this vicinity suggest that it probably underlies Ghost River at shallow depth, and that the disturbance noted above is closely related to this fault.

East of Orient Point, minor slickensiding in Lower Cathedral shales appears to be the only result of proximity to the McConnell thrust. To the south of this mountain, however, the thrust rises stratigraphically into the Pika? formation and overlying beds are strongly folded and faulted in a zone that appears restricted to a few tens of feet above the thrust (Plate 4C). On South Ghost River, Eldon limestones near the axis of the End Mountain syncline, and within a few hundred feet of the McConnell thrust, have been folded transverse to the syncline, to strike north 60 degrees east. Upstream from this, Eldon limestones overlying the thrust are massive, highly folded and fractured rocks that have probably been affected by the Costigan fault zone which occurs above them.

Foot Wall Structures

Upper Cretaceous strata beneath the McConnell fault are poorly exposed and no attempt was made to examine these beds for any distance east of the outcrop of the fault. The main areas of exposure in proximity to the thrust are on Burnt Timber Creek, Waiparous Creek, Ghost River, the east side of Orient Point, and South Ghost River.

Near Burnt Timber Creek, Belly River strata on the south plunge of the Panther River anticline outcrop beneath the thrust and are generally conformable in attitude with beds above the McConnell fault. East of Burnt Timber Creek, local changes in strike and steep dips suggest the presence of a fault in these beds on the east flank of the Panther River anticline. This fault may be related to the Panther River thrust fault but is apparently of limited throw.

Poorly exposed Belly River shales and sandstones outcrop at an elevation of 7400 feet on the eastern slopes of "Sheep Meadow" Mountain within a few tens of feet of overlying Upper Cathedral limestones but no attitude could be determined.

On Waiparous Creek, folded and faulted Belly River beds outcrop within 800 feet of Lower Cathedral dolomitic limestone and continue for several miles down this stream. Open folds striking north 30 degrees west are interrupted in this distance by local highly fractured zones and steeper dips which suggest the presence of thrust faults. The second south tributary of Waiparous Creek displays similar structures in the Belly River but outcrop is lacking in proximity to the McConnell thrust and attitudes are so variable that no attempt was made to correlate structures between the two streams. No outcrop of Upper Cretaceous beds was observed in the low-lying area between Waiparous Creek and Ghost River but talus blocks of Belly River sandstone observed within a few tens of feet overlying Cambrian beds at an elevation of 6500 feet on the east flank of Black Rock Mountain establish the presence of the thrust in that locality. On Ghost River, strata adjacent to the McConnell fault are exposed in a small highly fractured outcrop on the east bank. At this locality, Belly River sandstones and shales are gently folded beneath the fault into a small anticline and syncline, with one small south-dipping normal fault. The folds strike north 90 degrees east, plunge gently east, and exhibit dips up to 12 degrees.

Belly River strata also outcrop on a small tributary of Ghost River that rises on the east face of Orient Point. In this place Cambrian limestones of the Lower Cathedral formation outcrop

within 500 feet of folded and faulted Belly River sandstones. Strike of the Belly River beds varies from north 55 degrees west to north 70 degrees east and dips average 30 degrees, except in exposures nearest the fault, where the beds are so highly fractured that no attitude could be obtained. One thrust fault in the Belly River strikes about north 60 degrees east and dips about 25 degrees north.

On South Ghost River, Belly River strata east of the axis of the End Mountain syncline display general westerly and northerly dips averaging 25 degrees. On the west limb of this syncline, these beds strike north 45 degrees west and dip 30 degrees northeast beneath the McConnell thrust. In the river bed, an overturned syncline has an essentially horizontal east limb and west limb dipping 40 degrees west with a strike of north 20 degrees west (Plate 6A). About 1000 feet of strata including the uppermost beds of the Wapiabi formation are exposed west of the axis of the syncline, within 200 feet of Cambrian limestones above the McConnell thrust.

Orient Block

The area between the McConnell and Costigan thrusts is designated as the Orient block, after Orient Point near Devils Gap. This part of the McConnell thrust sheet is limited to the area south of Burnt Timber Creek by recent erosion, and extends 16 miles south to the valley of the South Ghost River, which has cut through the Orient block to expose Wapiabi and Belly River strata of the Foothills sub-province. South of the map-area, small remnants of the Orient block remain on interstream divides, forming "End" Mountain on the south side of South Ghost River, an unnamed prominence between the forks of Bowfort Creek, and Mt. Yamnuska north of Bow River

(see Clark, 1954, pl. 1). Within the Ghost River area, strata of this block are folded into a broad, plunging syncline which narrows to the south to become the End Mountain syncline of Clark. Strata exposed within this panel of Palaeozoic rocks range in age from Lower Cathedral to Palliser. Faulting is of little importance in this unit except along the eastern side above the McConnell thrust, where the imbricate belt of Black Rock Mountain appears. The Ghost River fault transects at least the western part of the Orient block along Ghost River.

Northern Part of Orient Block

North of Ghost River, the Orient block has a maximum present width, including the Black Rock imbricate belt, of 5 miles and a length of 9 miles. Dips within this area are gentle, averaging about 10 degrees, and the strike is extremely variable. At the north end of the block, strata within it have been folded into three anticline-syncline pairs, all of which plunge relatively steeply to the south. From west to east these folds consist of:

A-1 The westernmost observed fold in the Orient block is a south plunging anticline, hidden for much of its length beneath the Costigan block, and present for a distance of 6 miles north of Ghost River with an average strike of north 30 degrees west. This fold was observed near the head of Waiparous Creek in beds of the Eldon formation and passes beneath Castle Peak to follow the western slopes of Devils Head in the same unit. The Stephen and Upper Cathedral formations outcrop in the core of the fold on the north side of Ghost River. Maximum dips on the limbs of this anticline vary between 5 and 15 degrees, and the structure plunges south 1200 feet, or an

average of 3.6 degrees. The western limb of this fold is assumed to parallel the dip of the Costigan block west of the trace of the Costigan fault, and this interpretation is incorporated in Plate 2.

S-2 East of the above anticline, and parallel to it, is a complementary syncline with a somewhat greater south plunge of 3.7 degrees, amounting to 1800 feet over the length of 6 miles. On Burnt Timber Creek the west limb of the fold is cut by the Costigan thrust, the east limb remaining in beds of the Eldon, Pika? and Ghost River formations. South of Waiparous Creek the axis of the fold is overriden by the Costigan fault, and to the south passes beneath Castle Peak and Devils Head in beds of the Fairholme group. On the north side of Ghost River the syncline is expressed as a shallow fold in Upper Cathedral and younger beds. Structural relief increases from almost zero to Burnt Timber Creek to about 200 feet near Ghost River. East limb dips vary from a maximum of 10 degrees west at the north end to 5 degrees west at the south.

A-3 An anticline present in beds of the Eldon and Pika? formations between Burnt Timber and Waiparous Creeks plunges south parallel to the preceeding syncline. On Waiparous Creek, Upper Cathedral beds are exposed in the core of the fold and on the next creek south a small window of Stephen shale outcrops near the fold axis. South of this, Eldon to Fairholme strata are exposed on the fold. South plunge of the anticline is 3.7 degrees, or 2000 feet to a point about 2 miles north of Ghost River, where the fold is replaced by a small thrust fault (F-3). Strike of this structure averages north 40 degrees west and structural relief varies from 400 feet at the north end of the fold to 100 feet where it becomes faulted. The present length of the unfaulted anticline is 6 miles.

Maximum dips on the limbs decrease southerly from 30 degrees to 3 degrees. A small thrust fault (slip about 100 feet) in the east limb of this anticline is exposed on the south side of Burnt Timber Creek, but was not observed elsewhere in the map-area.

S-4 East of the above anticline, a strongly south-plunging syncline-anticline pair are present near Waiparous Creek. The strike of the syncline is north 40 degrees west for 2 miles south of the McConnell fault trace. South of this the axis swings to assume a strike of north 70 degrees west for about 1 mile and the fold loses its identity as a distinct structure in the End Mountain syncline (S-6). Total plunge of this fold is 1500 feet or 4.6 degrees, and structural relief decreases southerly to zero from 400 feet north of Waiparous Creek. The fold has maximum dips on the limbs of 7 degrees west and 30 degrees east and is exposed in all strata from the Lower Cathedral to the Fairholme.

A-5 The complementary anticline to syncline S-4 has an axis lying about 3000 feet east of S-4 and is subparallel to it, having a strike in the northern portion of north 25 degrees west and in the south of north 65 degrees west. The fold plunges 1800 feet into the End Mountain syncline at an average rate of 8.5 degrees south. Structural relief decreases from a maximum of 600 feet at the north end. North of Waiparous Creek this fold is apparent in all strata from the Lower Cathedral formation to the Fairholme group and has maximum dips on the limbs of 10 degrees west and 17 degrees east. On Waiparous Creek the east limb of the fold, as expressed in beds of the Upper Cathedral, Stephen and Eldon formations, assumes a local vertical dip and is accompanied by minor faulting. South of this

creek the west limb flattens and disappears as the fold swings to the east.

S-6 The major fold of the Orient block is believed to be a continuation of the End Mountain syncline, mapped by Clark in the Bow River area. This structure has a length of 9 miles north of Ghost River, and extends another 8 miles to the south boundary of the map-area, being the only fold that crosses Ghost River without interruption. In that part of the syncline lying north of Ghost River, an average plunge of 2.4 degrees south results in a vertical drop of 2000 feet. Except on Burnt Timber Creek, where Lower Cathedral strata are present in the fold, the oldest beds exposed in the axial region are Eldon limestones. The structural relief of this syncline is in excess of 1000 feet, the entire east limb not being present. Any given horizon ranges from 1200 feet (at the north end), to 200 feet (at the south) lower than the highest point of the anticlines to the west, because of the more gentle plunge of this structure. North of Ghost River the strike averages north 30 degrees west for 3 miles and then swings to north 20 degrees west as far as Burnt Timber Creek. The strongest west limb dips are present near Waiparous Creek (see above) and these decrease to 5 degrees east near Ghost River. Maximum east limb dips average 15 degrees west.

Small-Scale Structures

In detail the structure of the northern part of the Orient block is more complex than indicated above. Small anticlinal folds are present in many exposures in the Orient block and are particularly well displayed along Waiparous Creek near the axis of the End

Description of Plates

Plate 5

McConnell thrust fault exposed on the South Ghost River (looking north).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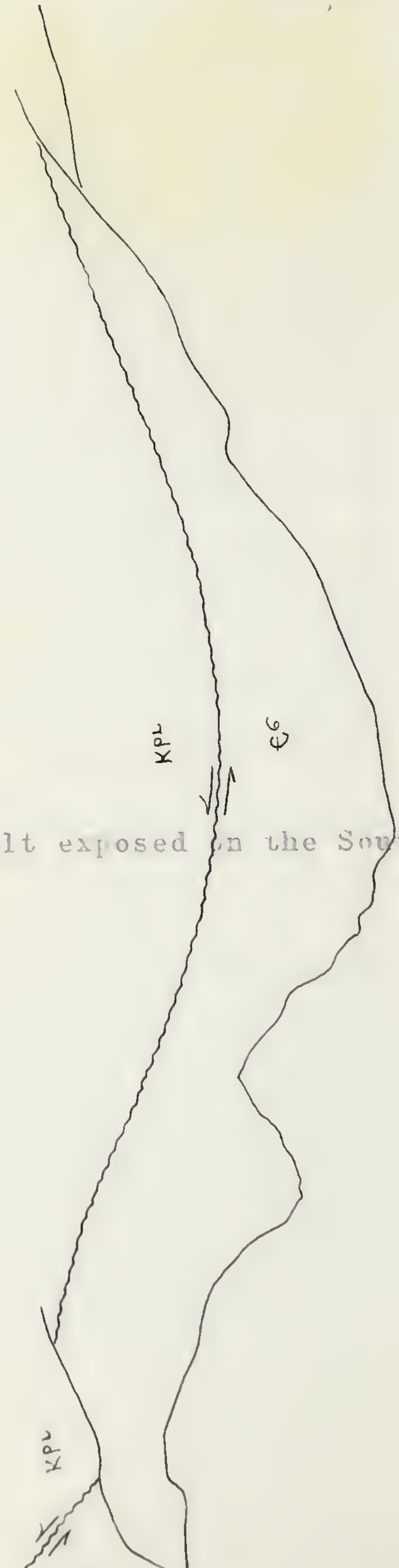
Description of Plates

Plate 5



McConnell thrust fault exposed on the South Ghost River (looking north).

Mountain syncline. In this place 14 individual south plunging folds with dips on the limbs of 5 to 10 degrees outcrop in the lowermost Eldon limestones in a distance of 1/2 mile. Similar folding is expressed in Upper Cathedral limestones on the crest of anticline (A-5). In other places, small anticlines that die out vertically, have thrust faulted east limbs, the thrust faults becoming parallel to the bedding in both directions from the fold. One structure of this type is exposed on the first south tributary of Waiparous Creek in beds of the Eldon formation. The fault has a slip of several tens of feet, dips 30 degrees west and flattens upwards to parallel the bedding, which is here close to horizontal. The fold developed where the thrust fault dips 30 degrees may be the result of drag. Similar folds exposed south of Johnson Creek are restricted in amplitude and length and frequently change into small thrust faults with a low h along strike. Offsets exposed on the inaccessible east-facing cliffs north and south of Waiparous Creek represent small faults whose nature could not be determined.

Southern Part of Orient Block

South of Ghost River, the most prominent fold in the Orient block is the End Mountain syncline, which traverses the map-area and continues south almost to Bow River. Between Ghost River and Devils Gap, Phantom Crag forms the east limb of the fold with an average dip of 10 degrees west (Plate 2A). The west limb of the syncline is cut by the thrust fault that originated in A-3 north of Ghost River. South of Devils Gap the west limb of the End Mountain syncline becomes more pronounced and exposes a near vertical succession of Eldon to Palliser beds. Dip of the east limb at Orient Point averages 10 degrees west. The youngest beds exposed in the Orient block are represented here by Palliser limestones that form the

uppermost cliffs of Orient Point (Plate 4C). The oldest strata outcropping along the axis of the fold are Upper Cathedral limestones in Devils Gap.

Two plunge depressions in the southern part of the End Mountain syncline are situated west of Phantom Crag and west of Orient Point. The more northerly of the two represents an additional 500 feet of plunge of the syncline from the north side of Ghost River. Between the two depressions, a relatively high axial position is situated near Devils Gap. From here, plunge into the northern depression is 2.1 degrees or a total of 600 feet. Plunge into the southern depression is also 600 feet for an average of 3.4 degrees. A pronounced north plunge of 5.7 degrees or 1000 feet is present between South Ghost River and Orient Point. The fault (F-3) referred to above as replacing anticline A-3 originates 2 miles north of Ghost River on the northeast slopes of Devils Head and has a sinuous outcrop south as far as Devils Gap where it is replaced by a small anticline on the west limb of the End Mountain syncline. It is arbitrarily considered to be a part of the Orient block, although throughout much of its length it is comparable in its relationships to faults of the Costigan fault zone. Slip on this fault is low north of Ghost River (700 feet) where the Upper Cathedral, Eldon, Pika and Ghost River beds are faulted on Upper Cathedral, Pika, Ghost River and Fairholme strata of the west limb of the End Mountain syncline. Between Ghost River and Devils Gap fault F-3 has an average dip slip of about 1000 feet. Lower Cathedral sandstones are present in the hanging wall of this fault on the south side of Ghost River, and the Ghost River tear fault apparently terminated eastward against F-3. The dip of fault (F-3) is variable

but averages 30 degrees west.

Black Rock Belt

Black Rock Mountain to the north of Ghost River, contains structures not typical of the general Ghost River area. This mountain consists of a great thickness of Middle Cambrian beds repeated by numerous small thrust faults (Plate 6B). In areas of good exposure, such as the uppermost half and eastern slopes of this mountain, the presence of the Stephen formation in the various thrust slices makes interpretation of the structure relatively straight forward. However, when exposures are incomplete, mapping of the various small faults becomes virtually impossible because of the difficulty of recognizing important faults in the badly shattered limestones of the Upper Cathedral and Eldon formations, and the inherent difficulty of identifying these two units in small outcrops.

Ten mappable thrust faults, plus inumerable smaller faults, were observed on Black Rock Mountain. All of these repeat the Stephen formation and have dip slips of up to 2000 feet but averaging about 500 feet. The general uniformity of movement on the thrusts has resulted in an unusual outcrop distribution on the mountain. Much of the eastern slope consists of limestones of the Eldon formation, followed to the west in the central part of the mountain by an irregular oblique belt of repeated Stephen shales and limestones. The entire west flank of the mountain is Upper Cathedral limestone. Faults may be traced into this west flank from the east but are generally unrecognizable in the badly fractured and irregularly folded, massive limestones. The lower western slopes of Black Rock Mountain contain many exposures of Upper Cathedral limestone but attitudes are variable and the outcrops appear to be slumped.

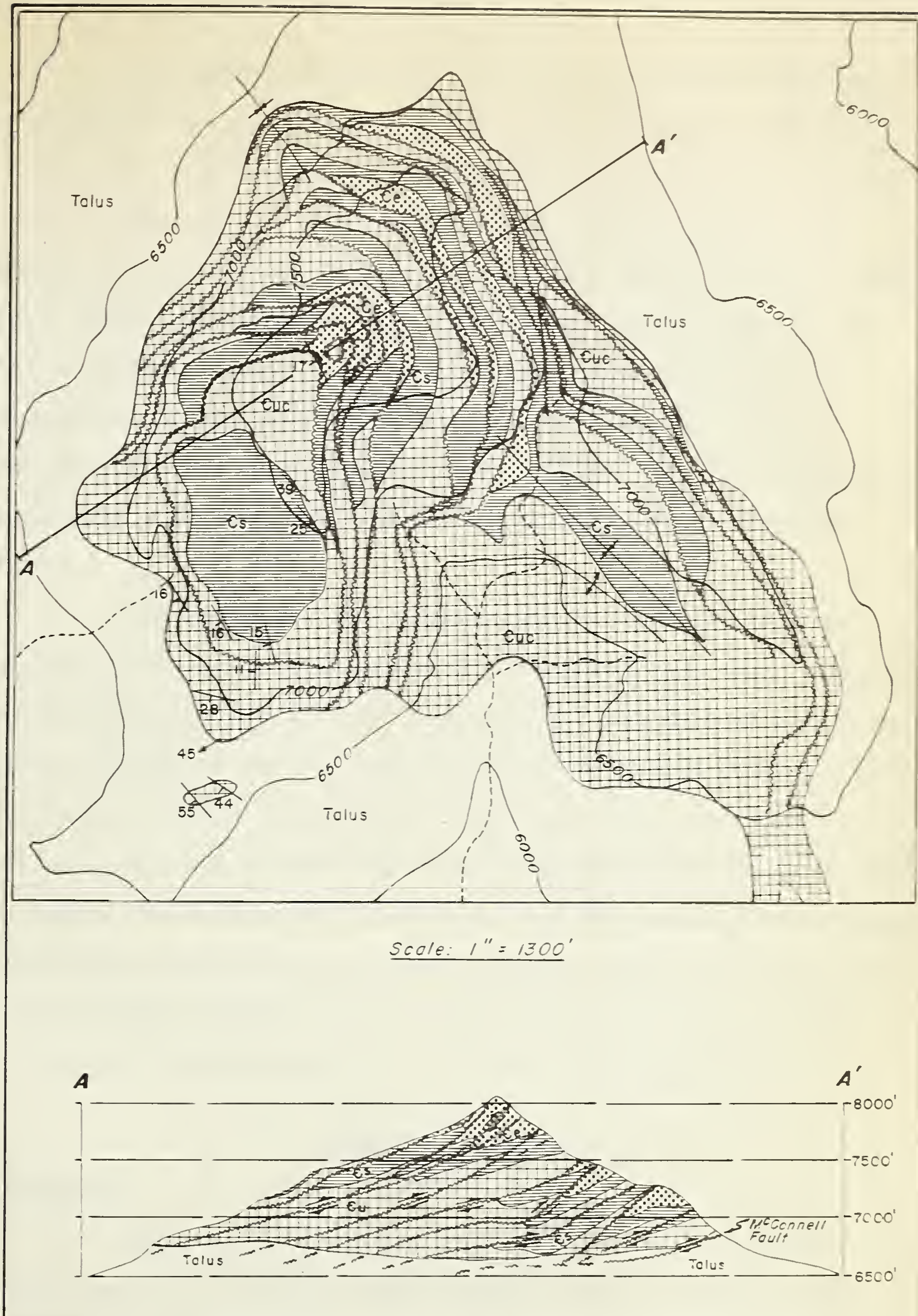


FIGURE 5

MAP AND STRUCTURE-SECTION A-A' THROUGH BLACK ROCK MOUNTAIN. (LEGEND SAME AS PLATE 1)

The Mountain front west of Black Rock Mountain comprises an uninterrupted succession of strata ranging from Lower Cathedral at the base to Fairholme at the top (Plate 2A). No evidence of the type of faulting observed on Black Rock Mountain was seen. This suggests that the small faults on this mountain must dip below ground level east of Ghost River. This conclusion, coupled with the fact that at Orient Point, and probably on Ghost River south of Black Rock Mountain, the above mentioned unfaulted succession occurs immediately above the McConnell fault, suggests that the imbrications present on Black Rock Mountain are all branches of the McConnell thrust.

The appearance of a similar type of faulting along the mountain front north of Waiparous Creek suggests that these exposures and the faulting on Black Rock Mountain were once part of a continuous belt of imbricate faulting, lying east of the present mountain front and largely removed by erosion. Both of the above mentioned areas are characterized by landsliding and slumping, due to the combination of highly broken Palaeozoic limestones resting on soft, non-resistant Belly River beds below the McConnell thrust. Dips on the faults are steeper (30-50 degrees) than the average for the McConnell thrust (10 degrees) and they appear to be gently concave upwards.

Costigan Fault

North Part

From its junction with the McConnell thrust on Burnt Timber Creek, the Costigan fault outcrops with an irregular trace beneath the Costigan thrust sheet south to Ghost River, where it is offset by the Ghost River transverse fault. The trace of the fault

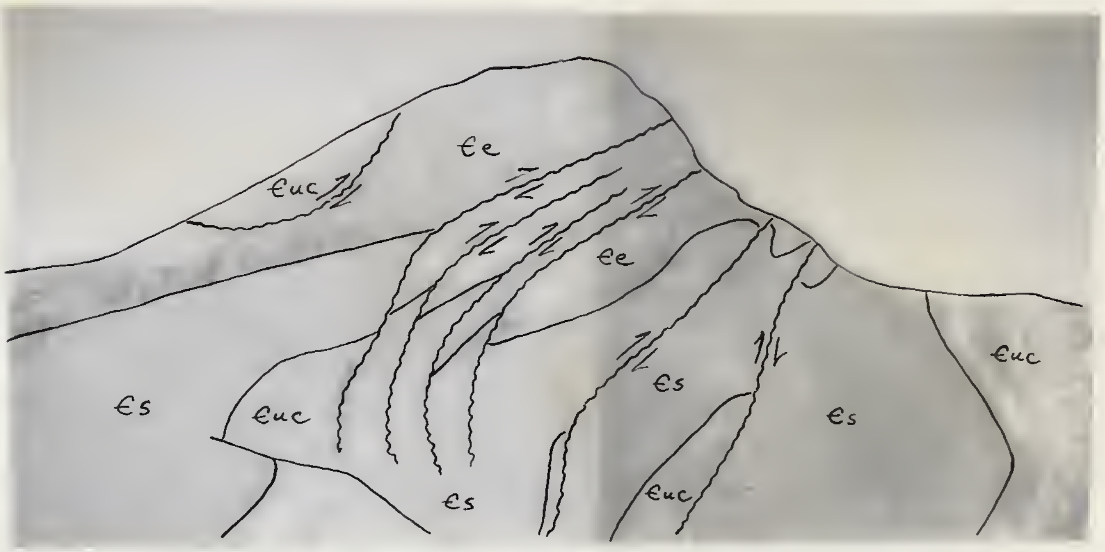
Description of Plates

Plate 6

A - Overturned syncline in Belly River beds beneath the McConnell fault (looking south across South Ghost River).

B - Thrust faults on Black Rock Mountain (looking north).

C - Costigan fault exposed on Devils Head (looking northwest across Ghost River).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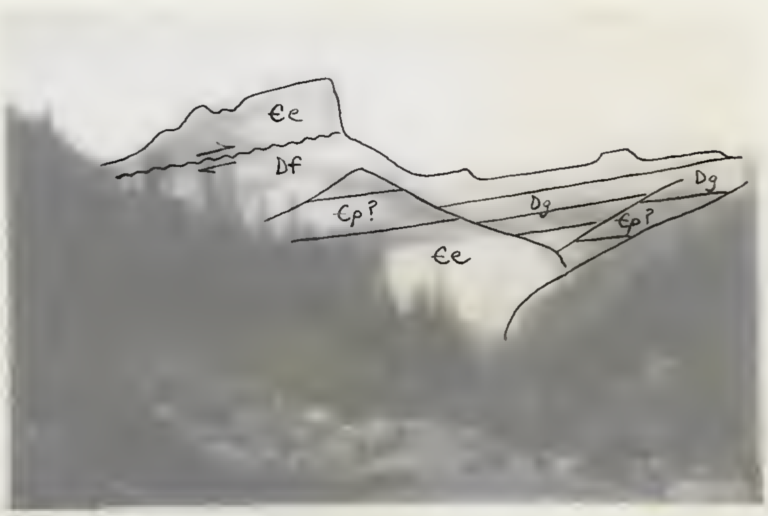
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Description of Plates

Plate 6

A - Overturned syncline in Belly River beds beneath the McConnell fault (looking south across South Ghost River).

B - Thrust faults on Black Rock Mountain (looking north).

C - Costigan fault exposed on Devils Head (looking northwest across Ghost River).

crosses Waiparous Creek and the next creek south near their headwaters and outcrops at an elevation of 8500 feet on the east flank of Castle Peak. From here it encircles the two southern ridges of this mountain and follows the west bank of a large tributary of Ghost River until it is offset by the Ghost River fault. The trace of the Costigan thrust encircles Devils Head forming the Devils Head klippe, (Plate 6C). The oldest beds exposed in the hanging wall of the fault are parts of the Lower Cathedral formation outcropping on Burnt Timber and Waiparous Creeks. Throughout most of its length, the Costigan fault brings Upper Cathedral limestones on younger beds, however, at its easternmost exposures, on Devils Head, the fault has risen into the Eldon formation. Footwall strata in the northern part of the Costigan fault vary from the Lower Cathedral formation, on Burnt Timber Creek, to high Fairholme group on Devils Head. The strike of the fault varies from North 30 degrees west to North 35 degrees west and the dip varies from a maximum of 25 degrees west on Burnt Timber Creek to a minimum of 5 degrees west at Castle Peak, with a general decrease in dip in an easterly direction. On the Devils Head klippe h is 5 degrees west and at Castle Peak it is 3 degrees west. In individual exposures the fault is essentially parallel to the bedding (i.e. h = 0 degrees). Areal considerations suggest that h is probably not much in excess of 3 degrees west for that portion of the fault exposed in the area. The higher value at Devils Head possibly shows a significant trend in an easterly direction.

f for the Costigan fault has considerably higher values in the map-area than h and permits of closer measurement. On the ridge south of Waiparous Creek the local f is 11 degrees east (Plate 8A).

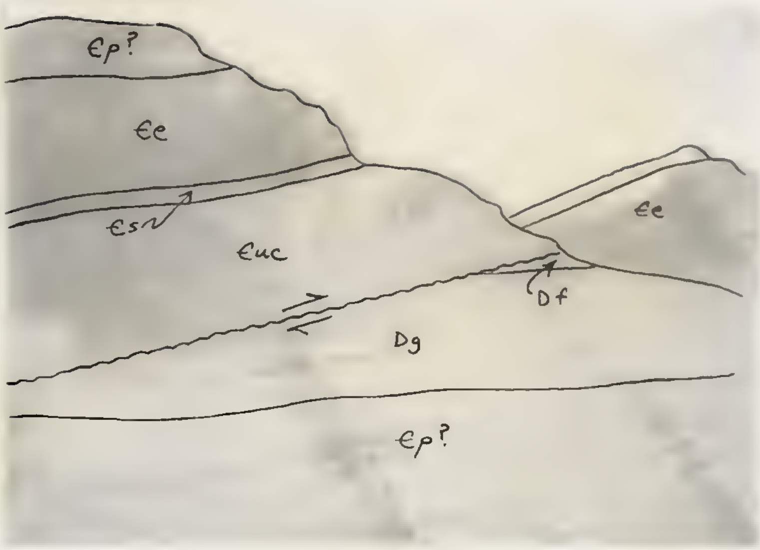
Description of Plates

Plate 7

A - Costigan fault exposed south of Waiparous Creek (looking northwest).

B - Costigan fault and branch on south side of Castle Peak (looking northwest).

C - Costigan fault on south bank of Ghost River (looking southeast).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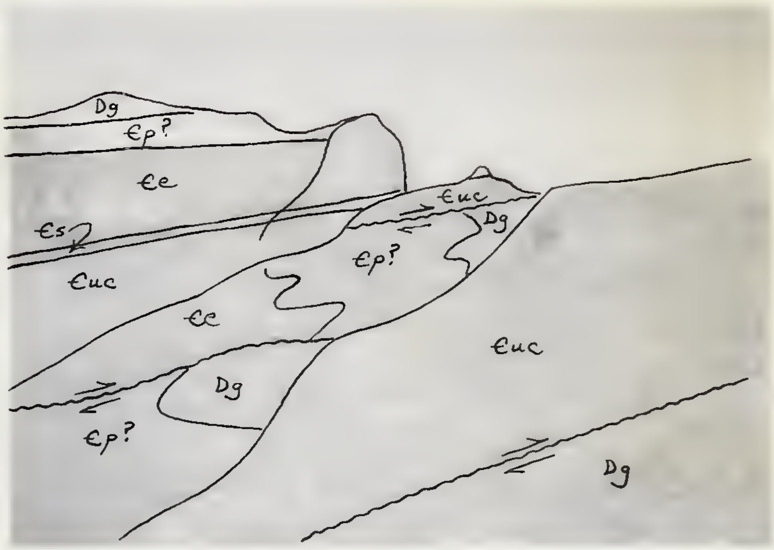
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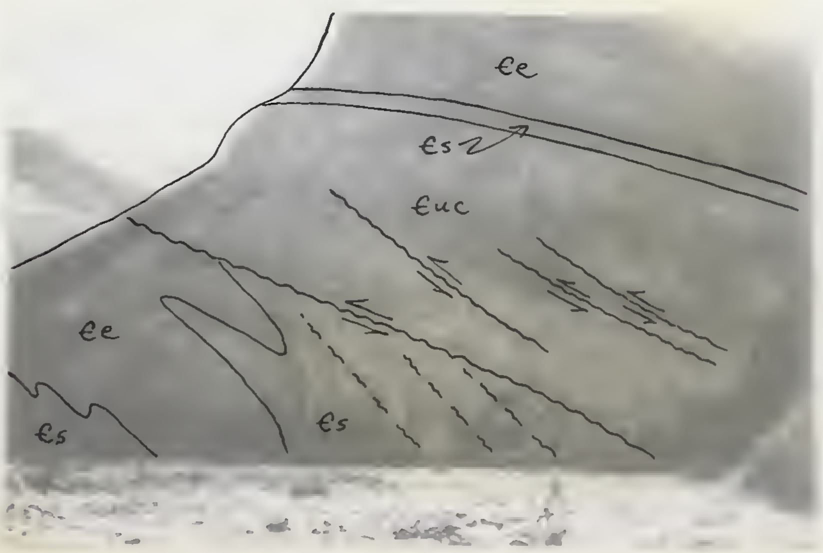
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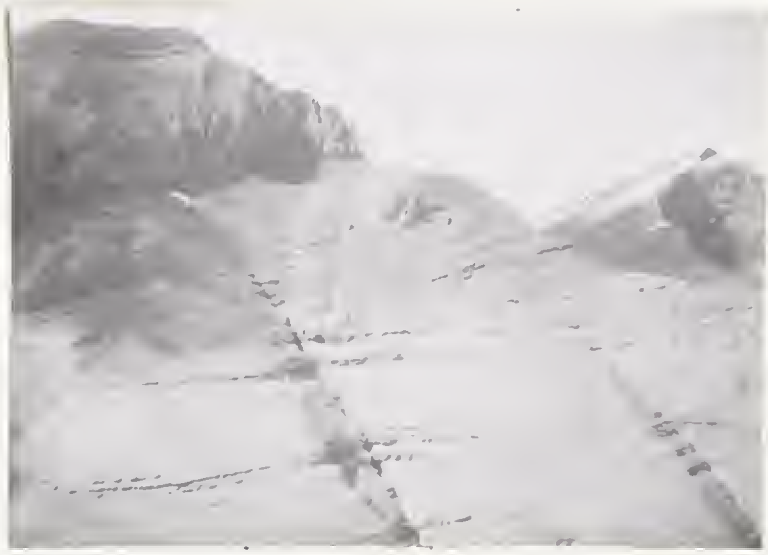
Description of Plates

Plate 7

A - Costigan fault exposed south of Waiparous Creek (looking northwest).

B - Costigan fault and branch on south side of Castle Peak (looking northwest).

C - Costigan fault on south bank of Ghost River (looking southeast).



Elsewhere f averages 14 degrees east and reaches a maximum of 19 degrees east at Devils Head. Local measurements of this angle are not possible south of Castle Peak because of the presence of secondary structures in the footwall beds.

f averages 10 degrees east, west of Devils Head in the most westerly exposures of the fault and this is thought to reflect a progressive decrease in value of this angle in a westerly direction. Progressive variations in the values of h and f are thought to provide a clue to the relative time of formation of this fault and are discussed more fully under the section devoted to structural history.

Small-Scale Structures

On the south flank of Castle Peak, the Costigan fault has two branches, and associated beds are strongly contorted and overturned (Figure 9, structure-section C-C'). The uppermost fault is the Costigan fault proper, and has a dip slip of at least 15,000 feet. Along the east flank of the mountain, Upper Cathedral limestones are thrust upon beds low in the Fairholme group. Upper Cathedral beds remain the immediate hanging wall beds south to Ghost River, but beds in the footwall of the fault are upturned and strongly folded along the south side of Castle Peak, and Ghost River and Pika? beds are rapidly truncated in a westerly direction. South of Castle Peak footwall beds are the Eldon formation as far south as Ghost River.

The lower fault has maximum slip along the south flank of Castle Peak of about 1500 feet and decreases rapidly in throw to the north and south. It is absent on Devils Head, less than 1 mile south and dies out rapidly in beds of the Fairholme group on the east flank of Castle Peak. Beds of Eldon to Fairholme age are strongly folded

between the two faults into a series of anticlines and synclines whose axes dip about 20 degrees west and are sub-parallel to the adjacent thrust faults which have a local west dip of 10 to 15 degrees. On the east slopes of Castle Peak, basal Fairholme beds contain two isoclinal synclines with an intervening anticline. Further west, Eldon limestones have been folded into two anticlines with associated syncline (Plate 7B).

Beneath the Costigan fault and its lesser branch, strata of Eldon to Fairholme age have been disturbed and locally overturned along the west limb of syncline (S-2) in a zone extending for about 100 feet from the faults. To the north of Castle Peak, little local disturbance is apparent in beds adjacent to the Costigan fault (Plate 7A). Small splays from the main fault appear in the hanging wall on Devils Head where the Stephen formation is displaced about 100 feet, and north of Waiparous Creek where Lower Cathedral beds are brought into juxtaposition with upper Cathedral limestones. Three small thrust faults that cut Upper Cathedral beds above the McConnell fault north of Burnt Timber Creek are associated with minor folds and may represent a small remnant of the Orient block at that locality.

South Part

South of the Ghost River fault a profound change occurs in the relationships of the Costigan fault. The dip slip decreases from 22,000 to 11,000 feet and folding becomes important as a shortening mechanism. Three thrust faults appear to the east of the Costigan fault near Ghost River and converge to the south to form a fault zone containing 3 to 4 westerly dipping thrust faults.

Beds ranging from Upper Cathedral to Fairholme are involved in the faulting. Aggregate dip slip on the faults of this zone varies from 8000 to 11,000 feet and this combined with shortening by folding of from 2000 to 4000 feet results in average shortening across the zone of 12,000 feet. The details of this faulted belt were not worked out in the field due to the difficulty of identifying horizons and important faults in the highly fractured and folded massive Cambrian limestones. Intense folding, calcite veining and frequent abrupt reversals in dip complicate the interpretation in an area that is largely inaccessible. Calcite-filled feather joints were observed with irregular trends, and much of the limestone is seen in hand specimen to be finely fractured.

The easternmost thrust fault of this belt overrides the vertical west limb of the End Mountain syncline between Devils Gap and South Ghost River and probably branches from the McConnell thrust a short distance west of the trace of the latter fault on South Ghost River. The Banff-Exshaw map (Miller, 1957) suggests that this fault zone continues south, possibly as a single thrust, almost to Bow River, where it outcrops in the saddle west of Mt. Yamnuska (see Clark, 1954, Plate 1).

Costigan Block

Much of the western half of the map-area is underlain by Palaeozoic strata of the Costigan block named by reason of its striking development in the vicinity of Mount Costigan between Ghost River and Lake Minnewanka.

The highest beds included in the Costigan block belong to the Spray River formation and are overlain by the Exshaw thrust along the western side of the map-area. Strata immediately above the

Costigan fault are of Upper Cathedral age with two small wedges of Lower Cathedral appearing at the north end of the fault on Waiparous and Burnt Timber Creeks. Structure within the block is essentially that of a westerly dipping homocline with dips increasing from an average of 10 degrees along the eastern edge of the sheet to 30 degrees further west. A change in dip from 20 degrees west, north of the Ghost River fault to 30 degrees west to the south is believed due to movement of the Ghost River fault and will be referred to below.

North of Ghost River, Mississippian to Triassic beds of the Costigan block have been folded beneath the Exshaw fault. These folds do not continue south of the Ghost River fault and are thought to have a relationship to the formation of this latter fault. North of Burnt Timber Creek the Costigan block swings slightly west from the normal strike of north 30 degrees west to north 75 degrees west, is underlain by the McConnell thrust and strikes into a complex unmapped area near North Burnt Timber Creek. South of the map-area the block continues to and beyond Bow River and is partially underlain by the McConnell thrust in this distance. At Bow River it forms the Mountain front above the McConnell thrust.

Exshaw Fault

Palaeozoic and Mesozoic rocks along the western side of the map-area are considered to be part of the Exshaw thrust sheet that forms a prominent part of the Front Ranges along Bow River. The fault was named by Clark (1954, p. 44) near Bow River where limestones of the Palliser formation are thrust on the Spray River, Rocky Mountain and Rundle groups. According to Clark the fault has a dip of up to 60 degrees west and strata within the thrust sheet dip 40-65

degrees west. The fault cuts beds in the footwall at a relatively high angle (f) as evidenced by the fact that footwall beds are Triassic in topographically high positions of the fault trace and Mississippian in the valleys. According to Clark, the fault diminished in throw south of Bow River and appears to be dying out in a southerly direction.

North of Bow River the fault rises stratigraphically in the hanging wall to bring Banff against Spray River near the head of Exshaw Creek. Miller (1957) shows this fault as rising into beds of the Rundle group at Lake Minnewanka, where footwall beds are still cut at a high angle (f) by the thrust.

Behavior of the thrust in the Ghost River area is similar to that further south with the fault being sub-parallel to Rundle strata of the hanging wall, and cutting footwall beds of Rundle to Triassic age, at an angle (f) of about 10 degrees. In the map-area the Exshaw thrust sheet has a dip averaging 40 degrees and the dip of the fault is close to this. The behavior of the Exshaw fault to the north of the map-area is not known. It should be present a short distance west of the Mountain front in the Panther River area. Clark (p. 44) suggests that this fault may be a branch of the McConnell thrust. The Exshaw fault must flatten at depth to retain the displacement indicated by the surface exposures and would probably not join the McConnell thrust for many miles west of the Ghost River area.

Dip slip on the Exshaw thrust averages in excess of 6000 feet south of the Ghost River but decreases progressively to the north of the Ghost River fault from about 3000 feet to 1000 feet at the northern edge of the map-area. North of Ghost River, folds in the Costigan block immediately below the Exshaw thrust appear to be

related to the latter structure. These folds consist of an anticline on the west which strikes north 30 degrees west and has maximum structural relief of about 1000 feet. The fold has maximum east limb dips of 65 degrees east and south plunge of 1000 feet. Rundle to Spray River beds outcrop on the crest of the fold. The west limb of the fold dips up to 45 degrees west and is overriden by the Exshaw thrust. The syncline to the east has little plunge and is represented along the axis by Rundle to Spray River beds. The east limb of this fold is the Costigan block homocline.

Exshaw Thrust Sheet

Little time was devoted in the field to an examination of the Exshaw thrust sheet. Strike of this structure averages north 32 degrees west, south of Ghost River and north 25 degrees west to the north, with an average dip near the top of the Palaeozoic succession of 40 degrees west. Rundle to Spray River beds are exposed in the Exshaw thrust sheet east of Ghost River, and a considerable thickness of younger (Jurassic, Cretaceous) strata are present west of Ghost River. As observed from a distance, these younger beds are locally highly disturbed beneath a large thrust fault that underlies the mountains west of the river. Mapping in the Banff-Exshaw area (Miller, 1957) shows the presence of a north plunging syncline in Palaeozoic and Triassic rocks of the Exshaw thrust sheet near Lake Minnewanka. A similar south plunging structure is suggested by the topography at the head of Ghost River.

Ghost River Fault

The east-west portion of the Ghost River valley is occupied for much of its length by an important transverse structure, herein named the Ghost River fault. The fault is concealed beneath alluvium in the valley bottom for most of its length, its presence being

inferred in most places on the basis of structural differences across the valley. This structure offsets strata of the Costigan block and the western part of the Orient block. It may affect the Exshaw thrust sheet and the eastern part of the Orient block but no evidence to suggest this was obtained in the field.

Average dip of the Costigan block south of Ghost River is 5-10 degrees steeper than that of equivalent beds to the north. This results in offset of equivalent horizons in a horizontal direction of from 500 to 1500 feet along the fault. Other evidence for the presence of the fault in the Costigan block is found at a promontory facing into the Ghost River valley from the south near the Banff-Rundle contact. At this place, although the Banff is comparable in thickness to other localities, limestones of this formation are highly folded at the northern end of the exposure. This disturbance is interpreted as indicating proximity to the Ghost River fault, which would be expected to be a short distance north of this outcrop.

Offset of the Costigan fault by the Ghost River fault is inferred on the basis of absence of Lower Cathedral formation above the former north of Ghost River. An almost complete thickness of the Upper Cathedral formation is exposed above the thrust on the south side of Ghost River. In view of the higher elevation of the Upper Cathedral north of the river, Lower Cathedral strata should appear above the fault if it maintains its trend to the north. No evidence of the presence of the distinctive sandstones and shales of this unit was observed and the thrust must be at a higher elevation north of the Ghost River fault since it is still in Upper Cathedral beds.

Below the Costigan fault, shales of the Stephen formation on the south side of Ghost River oppose Eldon limestones to the north.

Further east, beds on each side of the river are at about the same elevation to a point 1½ miles east of the Costigan thrust, where the Ghost River fault leaves the valley floor and traverses a steep north-facing hillside. The fault surface was not observed because of its inaccessibility, but Lower Cathedral sandstones are brought into contact with high Upper Cathedral beds on the south side. The north wall is here composed of faulted sandstones of the Lower Cathedral.

Immediately east of this exposure, a small thrust fault (F-3), crosses Ghost River and east of this structures across the valley appear conformable. This is far east as the Ghost River fault could be traced with certainty although it is not impossible that it could extend east across Black Rock Mountain as far as the outcrop of the McConnell thrust.

Relationships across this fault are puzzling. The strike averages north 87 degrees east, making an angle of 35 degrees with a normal to the general strike in the area, and the dip is near-vertical. This strike is strongly suggestive of one direction of a conjugate shear set, oriented about a maximum principal stress trending north 55 degrees east. This conclusion is contradicted by the occurrence of strata in both the Costigan and Orient blocks at higher elevations on the north side of the fault than on the south. If we make the reasonable assumption that the Ghost River fault extends no deeper than the McConnell thrust, and if we also assume that h for the hanging wall of the McConnell thrust opens to the west and is constant across Ghost River, then the advanced side of such a tear fault would rise (because of h) to occupy a position higher than the retarded side. On this basis the north side of the fault would be advanced, since it is structurally higher. If the Ghost

River fault was one member of a conjugate shear set, the south side would be the advanced side and should therefore be higher.

Added to this contradiction is the fact, previously referred to, that the north part of the Costigan fault has a dip slip of at least 22,000 feet, whereas the south part has only 11,000 feet. The Stephen formation, where it is terminated in the hanging wall of the Costigan fault, is 600 feet lower and approximately 2000 feet further west (across the strike) on the north side of the Ghost River fault than on the south side. The greater movement on the Costigan fault north of Ghost River is not consistent with displacement on a conjugate shear.

STRUCTURAL HISTORY

An attempt is here made to reconstruct the various stages in the development of the structures observed in the Ghost River area and specifically to relate the sequence of formation on the faults exposed at the surface. Any attempt at reconstruction of the structural history of an area such as this is fraught with difficulty since it is only when one begins an undertaking of this type that it becomes apparent what a small portion of the overall structure is available for observation. The following explanation therefore will hinge largely on several initial assumptions, based to some extent on analogies with other areas in the western Alberta disturbed belt. Several major structures are present in and near the Ghost River area, and an explanation will be offered for each of these.

The youngest rocks involved in the structures of the Ghost River area are continental sandstones and shales of the Belly River formation of Upper Cretaceous age. East of the map-area, this formation is overlain by Paleocene Paskapoo strata which are also faulted and folded in the Foothills belt. All structures in the Ghost River area are therefore considered to have been formed during the Laramide Orogeny, of post-Paleocene age. All the events presented below are considered to have occurred entirely within this orogeny and, although a certain sequence of structural events is presented, the various stages undoubtedly formed during continuous deformation and are largely contemporaneous.

The most obvious feature of the area is the McConnell thrust sheet, divided longitudinally into two segments by the Costigan branch of the McConnell thrust and by a pronounced change in dip.

To the north of the Ghost River area, beneath the McConnell thrust sheet, and striking towards the pronounced hinge in the McConnell sheet, is the Panther River anticline and its associated thrust fault. Other significant structures in the area are the Ghost River transverse fault, and the Black Rock Mountain imbricate belt.

Initiation of the McConnell Fault

In any projection of thrust sheets to depth, it is necessary to know as closely as possible the value and orientation of the angles h and f for the thrust fault. Normally h opens to the west, roughly perpendicular to the present structural trend, and is expressed in outcrop by the progressive introduction of older strata above the fault in a westerly direction. This is not the case in the Ghost River area except along the eastern outcrop of the McConnell fault. Along Burnt Timber Creek for example, the Lower Cathedral formation is present on the north flank of "End" Mountain and is cut out by the thrust on the eastern side of the same peak in the expected manner. However, the thrust to the west of "End" Mountain appears to parallel the bedding in the Lower Cathedral formation ($h = 0$) and at the head of Burnt Timber Creek cuts out the Lower Cathedral in a northerly direction. Evidence from this locality and the klippe north of Burnt Timber Creek, suggests that along this stream h opens to the south rather than the west. Similarly, on South Ghost River, the fault appears to rise stratigraphically to the west from Lower Cathedral shales on the east flank of Orient Point, into the Pika? formation on the south end of Orient Point. From here h again opens to the west and the fault is located well down in the Eldon formation. As in the case of the outcrops along Burnt Timber Creek, this pattern of formations above the McConnell thrust

is representative of a local northerly original dip. A mechanical projection of the observed values of h surrounding the Ghost River salient would give a maximum thickness of about 1500 feet for the Lower Cathedral formation near Ghost River. The resulting pattern of formation distribution indicated in Figure 6 could be expected to result from two situations. In the first possibility, if the strata involved were essentially plane surfaces the original fracture must have been a curved break, concave upwards in longitudinal section and having a line of intersection with any given bed that was a curve, convex eastward. This requirement, of a fracture forming with a strongly curved strike, is at variance with conventional ideas regarding thrust faulting.

The second possibility assumes that the fault when formed was an essentially plane surface and that the strata were folded. If this were the case in the Ghost River area, the outcrop pattern would represent an original high (anticlinal) area. This is more in keeping with the evidence from many parts of the disturbed belt that suggests that thrust faulting originated on the east limbs of earlier anticlines (e.g. Panther River, see Hunt, 1956, p. 52). The outcrop pattern present in the Ghost River area would then permit of the following conclusions.

1. A doubly plunging anticlinal fold formed in the Palaeozoic rocks. (The actual fold may have been restricted to the post-Cambrian portion of the section in a manner similar to that suggested by the Panther River anticline.)
2. Thrust faulting occurred in the steeper, east limb of the fold, originating near the culmination of the anticline.

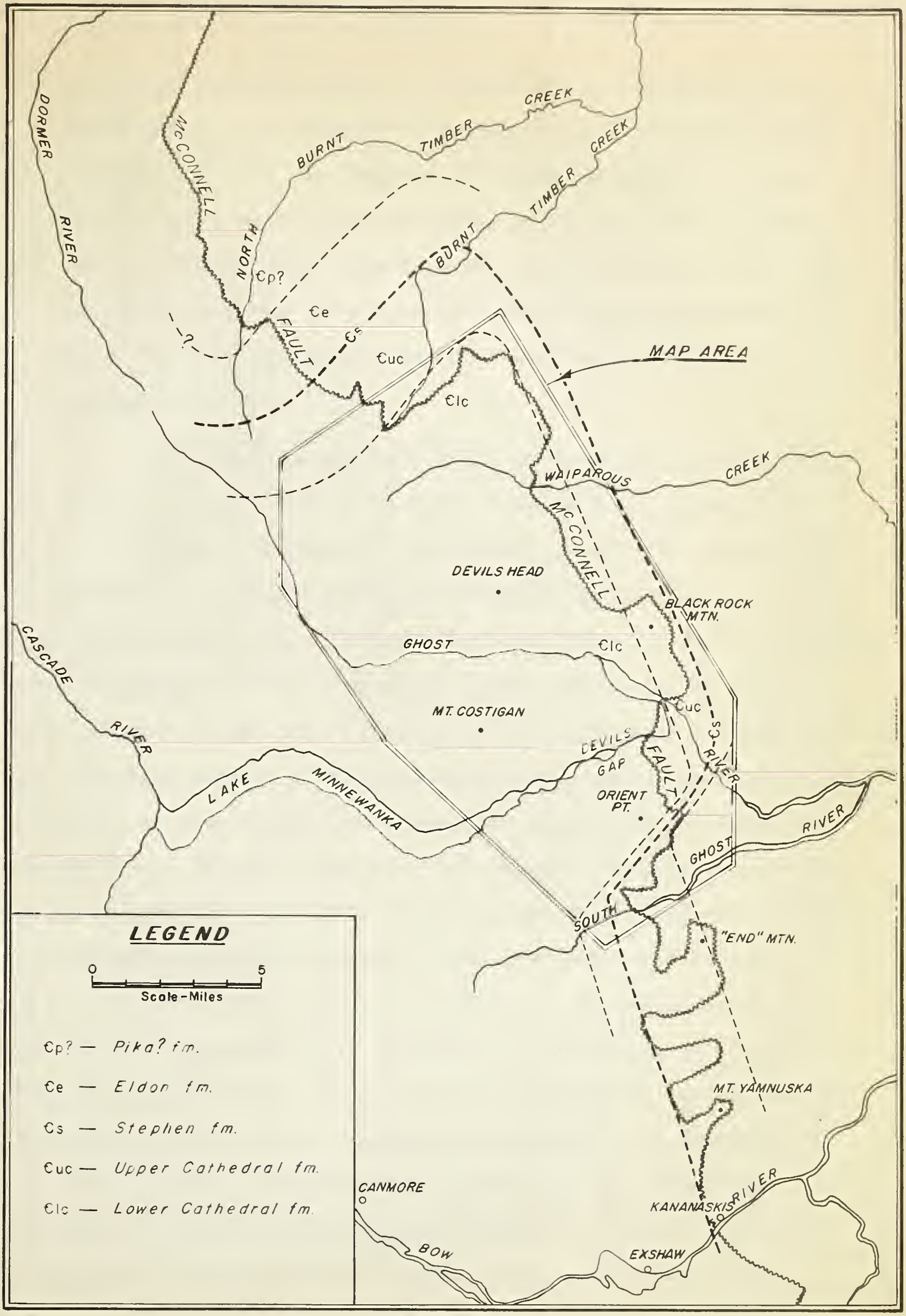


FIGURE 6

MAP SHOWING INFERRED LIMITS OF CAMBRIAN FORMATIONS ABOVE McCONNELL FAULT.

3. The fault extended itself in all directions. Tending to be a plane surface in a longitudinal direction, it cut successively younger strata as it traversed the plunging ends of the anticline. The longitudinal high point of the anticline, and the locus of the McConnell thrust, are now represented by the center of the Ghost River area. The transverse striking portions of Figure 6 would represent parts of the plunging ends of the original anticline.

The situation outlined above, of thrust faulting preceeded by folding, is at variance with ideas presented by Douglas (1950, p. 84) who implies that most of the folding in the Front Ranges and Foothills is a secondary process resulting from the action of thrust faults in several different ways. DeSitter (1956, p. 241) illustrates several examples of the formation of thrust faults in the steep limbs of anticlines. He also suggests that folds will be formed in the competent portion of the sedimentary sequence and that incompetent beds will to some extent have a passive or disharmonic relationship to the fold. In western Alberta, the presence of large anticlinal folds in competent palaeozoic strata, overlain by complexely folded and faulted incompetent Mesozoic shales and sandstones is well documented (e.g. Turner Valley). Folding of the magnitude of that observed at Panther River is difficult to account for by any of Douglas' fold types and seems to defy interpretation as drag folding on a large scale. It is, therefore, concluded that deformation in the central part of the Foothills and Front Ranges began with formation of folds in the competent Palaeozoic strata. Anticlines subsequently developed thrust faults in their steep east limbs.

Beyond the influence of the fold (i.e. in the incompetent Mesozoic beds and beneath the west limb of the anticline), the thrust fault would tend to follow its "usual" course with h and f between zero and the theoretical shearing angle. Where erosion has exposed the uppermost Palaeozoic strata above the thrust fault, as at Panther River, these beds usually form a large anticline. Where erosion has cut more deeply into the Palaeozoic succession, as it has in many of the Front Ranges, the anticlines are no longer evident. This is considered the case in the McConnell thrust sheet of the Ghost River area. At the ends of the thrust in Mount Head and Miette map-areas, the fault has risen stratigraphically into Upper Palaeozoic rocks which are characterized by folding of this type.

Panther River Fold

Coincident with the formation of the "McConnell" fold, another anticline formed en-echelon to the northeast. This was the prototype of the present Panther River anticline. Its presence as a doubly plunging anticline before the formation of the McConnell thrust is suggested by the relationships between the McConnell thrust and the underlying Panther River thrust sheet along Burnt Timber Creek (Figure 9, structure-section I-J-K).

A "normal" westerly original dip is indicated for the McConnell fault in the Panther River area by the relationships of the footwall beds where Wapiabi shales occur beneath the fault west of Belly River beds (Hunt, 1956).

In a longitudinal direction the relationships are anomalous, the McConnell fault plunges southerly across Burnt Timber Creek at 5 degrees whereas the underlying Belly River beds have a plunge of

30 degrees southerly. The same arguments apply here that were presented for the existance of a primary "McConnell" anticline. If the fault surface was plane in a longitudinal direction, a south plunging anticline must have existed to the "north" of Burnt Timber Creek. The culmination of the Panther River fold probably lay to the north of its present high point, since beds as old as Lower Cretaceous occur beneath the McConnell fault in that area.

Folding of the McConnell fault

Following formation of the McConnell thrust, movement began and amounted ultimately to tens of miles. Middle Cambrian beds were brought into juxtaposition with late Cretaceous sandstones in the Ghost River area. The stratigraphic throw totals about 17,000 feet and the magnitude of the dip slip may be appreciated by a comparison of the changes in thickness of individual formations across the fault as follows:

Table showing variation in thickness across McConnell fault

	Thickness below fault	Thickness above fault
Kootenay fm.	600*	3371*
Spray River fm.	390*	850*
Rocky Mtn. group	210*	330
Rundle group	1145*	1700
Banff fm.	665*	870

* Thicknesses taken from Hunt (1956)

After most of the movement had taken place on the fault; folding of beds beneath the thrust was accentuated and accompanied by the formation of the Panther River thrust. This had a higher dip than the McConnell fault and terminated upwards against the latter at a position approximately coincident with the axis of the End Mountain syncline (Figure 7, panel B). Continued movement on the

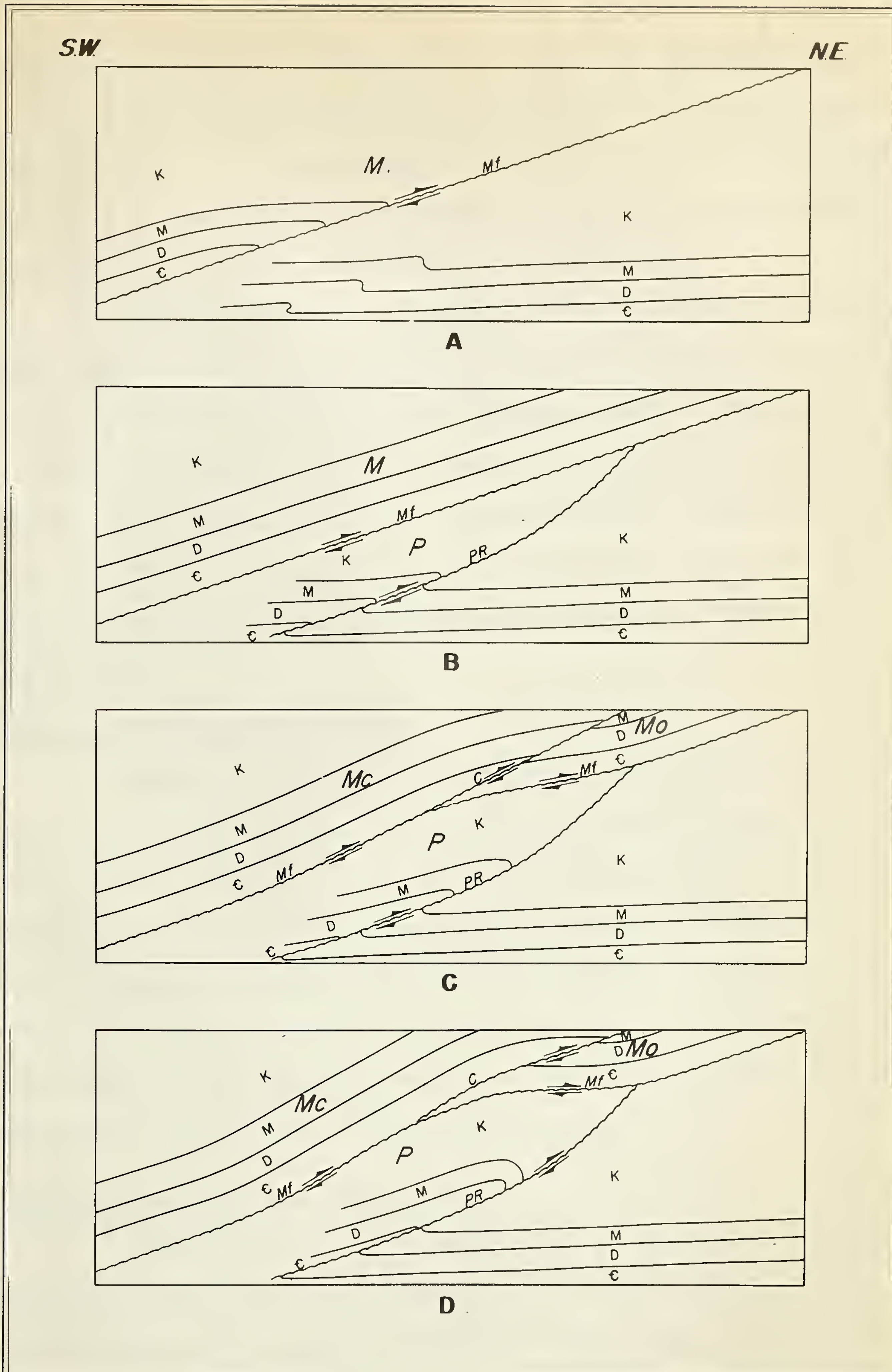


FIGURE 7

THEORETICAL STAGES IN THE FORMATION OF THE McCONNELL *Mf* , PANTHER RIVER *PR* , AND COSTIGAN *C* FAULTS DURING THE LARAMIDE OROGENY. CAMBRIAN Ꞓ , DEVONIAN D , MISSISSIPPIAN M , MESOZOIC K , McCONNELL THRUST SHEET *M* , COSTIGAN BLOCK *Mc*, ORIENT BLOCK *Mo* , PANTHER RIVER THRUST SHEET *P*

Panther River fault was hindered by the overlying competent sheet but was facilitated by accentuation of the fold. Forcing of these beds into the apex of the triangular area between the faults resulted in arching of the higher thrust (Figure 7, panel D). Maximum displacement of the latter is estimated to be 4000 feet.

Douglas (1958) has described sharp folding of the McConnell thrust sheet by the action of underlying small faults in the Highwood Range and broader folding of the Livingstone sheet at Savanna Creek by the same mechanism. Both of these are analogous to the structures exposed in the Ghost River area. Somewhat similar structures have been described by Collet (1927, p. 15) in the Alps as his second type of involution, where a younger nappe indents and folds the overlying one.

Formation of the Costigan Fault

Following folding of the McConnell thrust sheet, the fault underlying the west flank of the structure extended itself through the Palaeozoic rocks of the sheet as the Costigan fault. Evidence that this latter was moving during the folding of the McConnell sheet is provided by the decrease in dip from west to east of about 20 degrees. Maximum slip on the fault has taken place near Devils Head opposite the plunge depression in the Orient block and this is thought to be the locus of the Costigan thrust.

Plunge of the McConnell Thrust Sheet

Maximum uplift of the Panther River structure north of the map-area created marked south plunge in the Orient block. Similar uplift south of the map-area resulted in north plunge of this block with a plunge depression located near Ghost River. North-northwest differential movement on the McConnell fault is thought to be

indicated by the presence of transverse folds in the Belly River and Eldon formations on Ghost and South Ghost Rivers.

It is of some interest to attempt to quantitatively assess the action of the Panther River thrust sheet as it relates to longitudinal folding of the McConnell thrust sheet. Dip slip on the Panther River thrust is at a maximum near the present apex of the fold, and decreases to the south into the Ghost River area. Hunt (1959, Figure 1) indicates that the structural relief of the Panther River thrust sheet (i.e. the difference in elevation between a given horizon above and below the Panther River fault) is about 10,000 feet where the thrust has maximum dip slip. At this locality, beds of the Rundle group outcrop on the crest of the Panther River anticline. Along Burnt Timber Creek, the anticline has plunged southerly 9,000 feet and is represented at the surface by beds of the Belly River formation. If it is assumed that strata beneath the Panther River thrust sheet have negligible south plunge, it follows that the structural relief of the higher structure would be only 1000 feet on Burnt Timber Creek. Another 3000 feet of plunge is present on the McConnell thrust sheet between this creek and Ghost River. This suggests that, even allowing for 2000 feet of south plunge of beds beneath the Panther River sheet, this structure would have little relief at the latter place. This conclusion is supported by the interpretation of structure-section D-D' (Figure 9) where the vertical component of folding of the McConnell thrust sheet is about 1500 feet, and the End Mountain syncline lacks a well developed west flank.

It is perhaps to be expected that in a folded area, the presence of en-echelon structures would be more probable than the

formation of a single anticline with a marked depression along the axis. Assuming that the Panther River structure has essentially disappeared at the latitude of Ghost River, the fact that the McConnell thrust sheet is folded south of this at least as far as Bow River, suggests the presence of another anticline beneath the fault, and slightly en-echelon to the Panther River fold, rising to the south to appear at the surface in the Moose Mountain area south of Bow River. Such an en-echelon arrangement of folds near Ghost River would serve to explain some of the anomalous features associated with the Ghost River tear fault and would provide a more plausible explanation for the great plunge depression of the McConnell thrust sheet.

It is interesting to compare the rates of plunge of folds in the Orient block when the plunge of the End Mountain syncline is removed. In 5 miles between structure-sections A-A' and D-D', the syncline plunges 500 feet to the south. If this amount is subtracted from each of the other folds over the same distance, plunge for these becomes: A-1 - 600 feet; S-2 - 1000 feet; S-3 - 1000 feet; A-4 - 1200 feet; A-5 - 2100 feet. The resulting overall picture shows the End Mountain syncline flanked to the west by a broad anticlinal structure that plunges south and almost dies out at Ghost River. This is considered to reflect the behavior of the underlying Panther River thrust sheet, and supports the contention that this deeper structure is plunging south and that its influence on the McConnell thrust sheet is decreasing in this direction. This conclusion is supported by the observed relationships of the Panther River thrust sheet north of the Ghost River area. In Union Canadian Homestead Panther River 12-11 well (Lsd. 12, Sec. 11, Twp. 30, Rge. 11,

W5 Meridian) the Panther River thrust is a fault of some size, bringing Ghost River beds in contact with the Fernie group with a possible dip slip of over 2 miles (Hunt, 1956, p. 52). South from this well the thrust sheet plunges south relative to beds in the McConnell sheet, and the fault has not been positively identified, there being no evidence for large scale repetition of strata in Upper Cretaceous beds near Burnt Timber Creek. The fault in this vicinity must have a considerably decreased slip as compared with that at the latitude of the Union Canadian Homestead well.

Ghost River Fault

The Ghost River transverse fault appears to separate the Costigan zone into two segments, a northerly, simple thrust and a southern complex fault zone. A marked decrease in shortening occurs across the thrust from 22,000 feet on the north to 11,000 feet south of the Ghost River fault. This suggests strongly that this fault was in existence before the last movements on the Costigan thrust. Furthermore, if this fault were a simple shear rooted in the McConnell thrust, the south side would be advanced and would be expected to be structurally higher than the north. Also, more shortening might be expected on the advanced (south) side. Neither of these conditions occur: the north side has been shortened 11,000 feet in excess of the south on the Costigan fault, and now is structurally higher.

This fault is thought to have had a complex history, possibly originating as a shear fracture oriented about the regional maximum strees axis, and subsequently becoming the locus of differential movements between the north and south portions of the McConnell thrust sheet with the establishment of the plunge depression and formation of the Costigan thrust.

Just before formation of the Costigan thrust, uplift in the Panther River and South Ghost areas, caused rotation in a vertical plane around the Ghost River fault. At the east end of the fault, Lower Cathedral sandstones on the north were brought against Upper Cathedral limestone south of the fault. Fault F-3 had already formed at this time. On the west end of the tear fault, evidence for this rotation is had in the lower structural position of the Stephen formation north of the fault as compared to its position to the south.

When the Costigan fault formed in the McConnell thrust sheet, it originally had, near its intersection with the McConnell thrust, a relatively low h and f. Because of the curvature of the McConnell sheet, both h and f increased in value up the dip of the Costigan fault.

It has been shown that the north part of the Costigan fault had a slip of 22,000 feet, 11,000 feet greater than that on the south. At this time, longitudinal flexing of the Orient block resulted in greater movement on the north part as compared to the south. As movement on the fault occurred, low values of h would be brought into juxtaposition with high f values. The greater the slip the more pronounced would be the difference. It follows then that if the north side has a greater dip slip than the south, exposures at any given level, (in this case the ground surface) should show lower values of h on the north side of the Ghost River fault, and it also follows that the dip of the Costigan block on the north side will be less than that to the south. This is indeed the case near the Ghost River, where h increases from 5 degrees north of the Ghost River fault, to 10 degrees to the south, with a corresponding increase in average dip of the fault from 15 degrees to 30 degrees.

Because of local irregularities in the attitudes of both strata and faults, quantitative conclusions cannot be drawn regarding the relationships around the Ghost River fault, but qualitatively the observed relationships can be explained most readily by the above set of circumstances.

Exshaw Fault

The Exshaw thrust appears to have formed relatively late in the tectonic history of the Ghost River area. Occurring as it does on the west flank of the Costigan block, it probably represents a case of "back-limb" faulting as described by Douglas (1950, p. 88), possibly related to the action of the large thrust fault underlying the mountains west of Ghost River. Folding of strata in the footwall of the Exshaw fault north of this river and the absence of similar structures to the south, suggest that the Ghost River tear fault was in existance before formation of the Exshaw thrust. Although outcrop is lacking at the expected junction of these two faults in the Ghost River valley, the continuity in strike and dip of both the Exshaw fault and its overlying thrust sheet across the valley suggest that the thrust sheet is not offset by the Ghost River fault.

Dip slip on the Exshaw fault increases southerly across the map-area from about 1000 feet to about 6000 feet with a sudden increase of close to 3000 feet at Ghost River. As this thrust began to move, underlying beds north of the Ghost River were folded beneath the fault to result in shortening that south of the river was accomplished by faulting only, the pre-existing break at the Ghost River tear fault allowing a sudden change in structural style to take place longitudinally across this fault. Because of pre-existing differential movements across the tear fault, measured slip on the thrust is not a true measure of its movement.

Mechanical Principles

Charlesworth (1959, p. 253) has shown the applicability to the Rocky Mountains of stress systems determined by Hafner (1951). The original anticlines postulated for the Ghost River and Panther River areas formed within a stress system in which the maximum principal stress axis was oriented in an approximate north 55 degrees east direction and had a gentle northeasterly plunge. The minimum principal stress axis was in a vertical plane normal to the maximum principal stress axis and parallel to the original fold axes. The intermediate stress was horizontal, parallel to the fold axes. Concentric folding of the Palaeozoic succession in the areas involved resulted in the formation of thrust faults on the steeper east limbs of the folds as described by DeSitter (1956, p. 241). The thrust faults so formed would, beyond the influence of the fold, assume an original dip (h and f) that was a compromise between the theoretical shearing angle and a tendency to follow pre-existing planes of weakness along the bedding.

When the McConnell thrust sheet was folded by the action of the Panther River structure, the Costigan fault formed as an extension of the pre-existing western part of the former thrust and served to compensate for the plunge depression that resulted in the Orient block.

Formation of the Black Rock Belt of imbricate thrust faults has resulted from modification of the regional stress field as described by Anderson (1951). In the hanging wall of the McConnell thrust, lines of equal maximum principal stress were deflected upwards to become tangential to the fault. This resulted in the generation of a secondary principal stress parallel to the fault,

with two potential shear directions oriented about it. The lowermost of these would not develop because of the proximity of the McConnell thrust. The upper set tended to form with an angle to the master fault but probably had a smaller angle because of the influence of bedding planes that were sub-parallel to the thrust. Faults of the Black Rock belt are apparently of this type but the reason for their localization in this belt is not as readily apparent. As mentioned above, their restriction to the east limb of the End Mountain syncline would suggest that their formation may post-date the folding of the McConnell thrust sheet.

SUMMARY AND CONCLUSIONS

Initial deposits of the eastward transgressing Cambrian sea are represented in the Ghost River area by sandstones and shales probably derived from Precambrian rocks of the Canadian Shield of Albertella or lower Cathedral age. Above this deepening of the basin resulted in deposition of mainly carbonate rocks for the rest of Middle Cambrian time. A brief period of shallowing of the sea is thought to have occurred during Glossopleura or Stephen time.

Rocks of Upper Cambrian, Ordovician and Silurian ages are absent in the map-area, probably because of pre-Devonian uplift and erosion. Middle Devonian seas present in central Alberta during Elk Point time transgressed into the Ghost River area from the east, depositing the near shore Ghost River formation during Beaverhill Lake time. Progressive deepening of the Upper Devonian sea is represented by dolomites of the Fairholme group.

The Costigan and Ghost River faults, as well as the Black Rock imbricate belt, are thought to have originated as the result of folding of the McConnell thrust sheet by the underlying Panther River structure. Arguments have been presented for the initial formation of the McConnell and Panther River faults by thrust faulting of the steep limbs of early anticlines. Splay faults in the Black Rock belt and one branch of the Costigan thrust have formed as a result of modification of the regional stress field near the large thrust faults.

BIBLIOGRAPHY

Allan, J.A. (1915) Rocky Mountains Park, Alberta; Geol.Surv.Canada, Summ. Rept. (1914) pp. 42-43.

__________ (1916) Simpson Pass to Kananaskis, Rocky Mountains Park, Alberta; Geol. Surv. Canada, Summ. Rept. (1915) pp. 100-102.

Anderson, E.M. (1951) The Dynamics of Faulting and Dyke Formation with Application to Britain; Oliver and Boyd, Edinburgh.

Beach, H.H. (1943) Moose Mountain and Morley Map-Areas, Alberta; Geol. Surv. Canada, Mem. 236.

Belyea, H.R. (1952) Notes on the Devonian System of the North-Central Plains of Alberta; Geol. Surv. Canada, Paper 52-27.

__________ (1957) Correlation of Devonian Subsurface Formations, Southern Alberta; Geol. Surv. Canada, Paper 55-38.

__________ (1959) Devonian Elk Point Group, Central and Southern Alberta; Geol. Surv. Canada, Paper 59-2.

__________ (1956) Devonian Sediments of Bow Valley and adjacent areas; Alberta Soc. Pet. Geol., 6th Annual Field Conference, pp. 66-91.

Billings, M.P. (1954) Structural Geology; 2nd ed., Prentice-Hall, New York.

Burwash, R.A. (1957) Reconnaissance of Subsurface Precambrian of Alberta; Am. Assoc. Pet. Geol., Bull., vol. 41, pp. 70-103.

Charlesworth, H.A.K. (1959) Some Suggestions on the Structural Development of the Rocky Mountains in Canada; Alberta Soc. Pet. Geol., vol. 7, pp. 249-256.

Clark, L.M. (1949) Geology of the Rocky Mountain Front Ranges near Bow River, Alberta; Am. Assoc. Pet. Geol., Bull., vol. 33, pp. 614-633.

__________ (1954) Geology of the Rocky Mountain Front Ranges near Bow River, Alberta; Am. Assoc. Pet. Geol., Western Canada Sedimentary Basin; pp. 29-46.

Collet, L.M. et al (1927) The Structure of the Alps; Edward Arnold and Co., London.

Dahlstrom, C.D.A., and Henderson, G.G.L. (1959) Structural Geology of the Moose Mountain area, Alberta; Alberta Soc. Pet. Geol., 9th Annual Field Conference, pp. 53-62.

Dawson, G.M. (1886) Preliminary Report on the Physical and Geological Features of that portion of the Rocky Mountains between latitudes 49° and 51°30'. Geol., Nat. Hist. Surv., Canada; Annual Rept., vol. 1, 1885, pt. B.

Deiss, C. (1939) Cambrian Formations of Southwestern Alberta and Southeastern British Columbia; Geol. Soc. Am., Bull., vol. 50, pp. 951-1026.

DeSitter, L.U. (1956) Structural Geology, McGraw-Hill Co., N.Y.

deWit, R. (1956) The Ghost River Formation near Bow Valley; Alberta Soc. Pet. Geol., 6th Annual Field Conference, pp. 100-113.

________ and McLaren, D.J. (1950) Devonian Sections in the Rocky Mountains between Crowsnest Pass and Jasper, Alberta; Geol. Surv. Canada, Paper 50-23.

Douglas, R.J.W. (1956) Nordegg Alberta; Geol. Surv. Canada, Paper 55-34.

______________ (1958) Mount Head Map-Area, Alberta; Geol. Surv. Canada, Mem. 291.

______________ (1950) Callum Creek, Langford Creek, and Gap Map-Areas, Alberta; Geol. Surv. Canada, Mem. 255.

______________ (1956) George Creek, Alberta; Geol. Surv. Canada, Paper 55-39.

Dowling, J.B. (1905) Costigan Coal Field; Geol. Surv. Canada, Map 892.

Erdman, O.A. (1946) Cripple Creek, Alberta; Geol. Surv. Canada, Paper 46-22.

Folk, R.L. (1959) Petrology of Sedimentary Rocks; Hemphill's Austin, Texas.

Garland, G.D., and Burwash, R.A. (1959) Geophysical and Petrological Study of Precambrian of Central Alberta; Am. Assoc. Pete. Geol., Bull., vol. 43, pp. 790-806.

Goddard, E.N. (1951) Rock-Color Chart; Geol. Soc. Am.

Gussow, W.C. (1960) The Pre-Devonian Unconformity in North America; Int. Geol. Congress, XXI, Sess., Norden., Part XIX, pp. 158-163.

Hafner, W. (1951) Stress Distributions and Faulting; Bull. Geol. Soc. Am. vol. 62, pp. 373-398.

Hage, C.O. (1946) Dyson Creek, Alberta; Geol. Surv. Canada, Map 827A.

Harker, P., Hutchinson, R.D., and McLaren, D.J. (1954) The Sub-Devonian Unconformity in the Eastern Rocky Mountains of Canada; Am. Assoc. Pet. Geol., Western Canada Sedimentary Basin, pp. 48-67.

Hubbert, M.K. (1951) Mechanical Basis for Certain Familiar Geologic Structures; Geol. Soc. Am., Bull., Vol. 62, pp. 355-372.

Hunt, C.W. (1956) Panther Dome: A minor Orogen of the Canadian Cordillera; Alberta Soc. Pet. Geol., 6th Annual Field Conference, pp. 44-55.

__________ (1959) Developments at Panther River, 1956 to 1959; Alberta Soc. Pet. Geol., Jour., vol. 7, pp. 157-160.

Hutchinson, R.D. (1960) Middle Cambrian Fossils in Eastern Alberta; Alberta Soc. Pet. Geol., Jour. vol. 8, p. 137.

McConnell, R.G. (1887) Report on the Geological Structure of a portion of the Rocky Mountains; Geol. Surv. Canada, Annual Rept. 2, 1886, pt. D.

McKinstry, H.E. (1953) Shears of the Second Order; Amer. Jour. Sci., vol. 251, pp. 401-414.

McKinnon, F.A. (1942) A study of the Cambrian-Devonian contact at the front of the Mountains in Bow Valley, Alberta; MSc. Thesis, University of Alberta.

MacKay, B.R. (1929) Mountain Park Sheet, Alberta; Geol. Surv. Canada, Map 208A.

McLaren, D.J. (1954) Upper Devonian Rhynchonellid Zones in the Canadian Rocky Mountains; Am. Assoc. Pet. Geol., Western Canada Sedimentary Basin, pp. 159-181.

_____________ (1955) Devonian Formations in the Alberta Rocky Mountains between Bow and Athabasca Rivers; Geol. Surv. Canada, Bull. 35.

Miller, V.C., and Associates (1957) Preliminary Photogeologic Reconnaissance Map of the Banff-Exshaw Area, Alberta; V.C. Miller and Associates, Photogeologists, Calgary, Alberta.

Mountjoy, E.W. (1959) Miette, Alberta; Geol. Surv. Canada, Map 40-1959.

Nelson, S.J., and Rudy, H.R. (1959) Stratigraphic Position of the Shunda Formation; Alberta Soc. Pet. Geol., vol. 7, pp. 257-259.

North, F.K., and Henderson, G.G.L. (1954) Summary of the Geology of the Southern Rocky Mountains of Canada; Alberta Soc. Pet. Geol., 4th Annual Field Conference, pp. 82-100.

Patterson, J.R., and Storey, T.P. (1960) Caledonian Earth Movements in Western Canada; Int. Geol. Congress XXI Sess., Norden., Part XIX, pp. 150-157.

Raasch, C.O., and Campau, D.E. (1957) Cambrian Biostratigraphy of California Standard Parkland 4-12; Alberta Soc. Pet. Geol. Jour., vol. 5, pp. 140-144.

Rasetti, F. (1951) Middle Cambrian Stratigraphy and Faunas of the Canadian Rocky Mountains; Smith. Misc. Coll., vol. 116, no. 5.

Shimer, H.W. (1913) Spiriferids of the Lake Minnewanka Section, Alberta; Geol. Soc. Am. Bull., vol. 24, pp. 233-240.

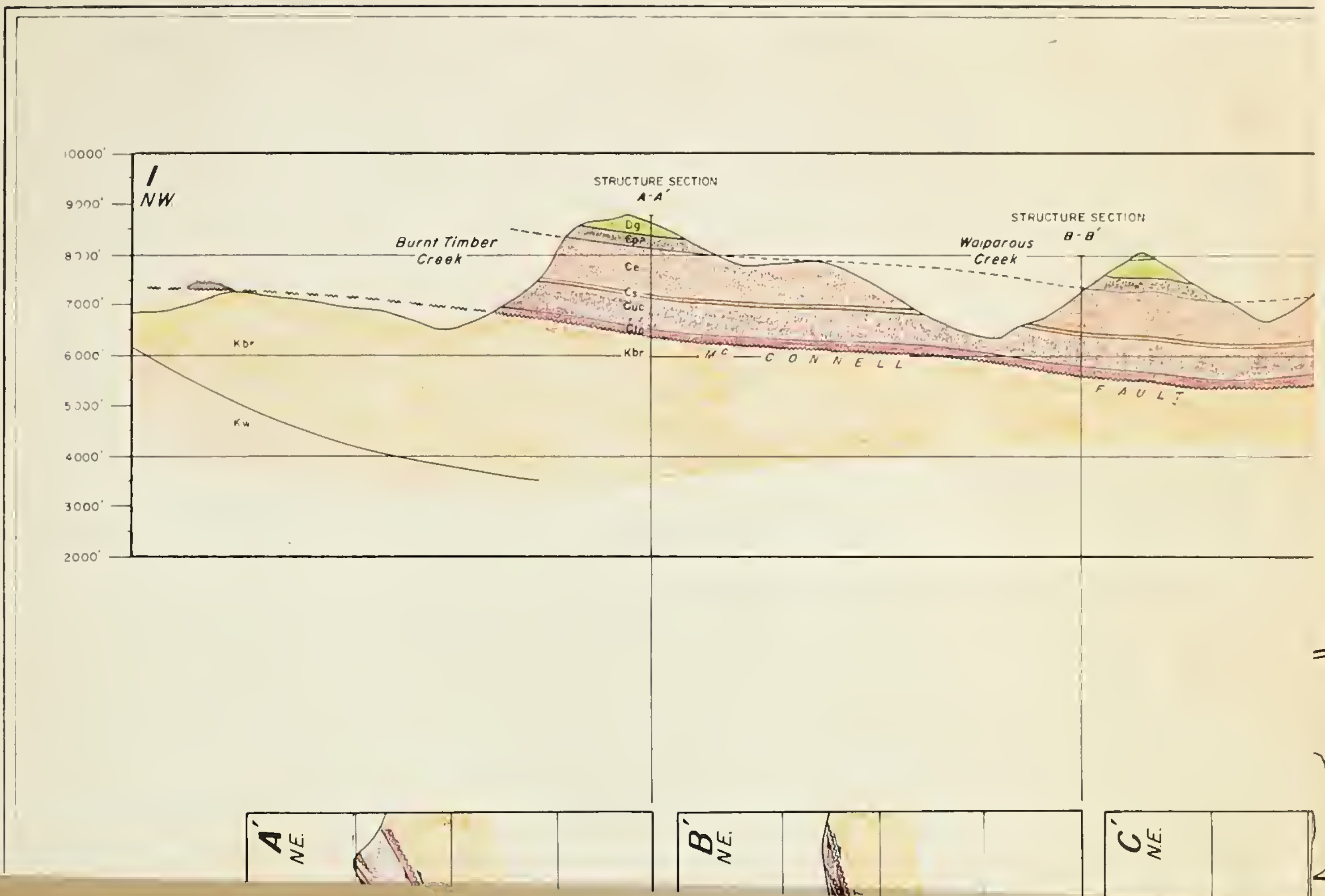
Shimer, H.W. (1926) Upper Paleozoic Faunas of the Lake Minnewanka Section, near Banff, Alberta; Geol. Surv. Canada, Mus. Bull. 42, pp. 1-84.

Van Hees, H. (1959) Middle Cambrian of the Southern Alberta Plains; Alberta Soc. Pet. Geol., 9th Annual Field Conference, pp. 73-85.

Wallcott, C.D. (1928) Pre-Devonian Palaeozoic Formations of the Cordilleran Provinces of Canada; Smith, Misc. Coll., vol. 75, pp. 175-353.

______________ (1923) Nomenclature of some Post Cambrian and Cambrian Cordilleran Formations; Smith, Misc. Coll., vol. 67, no. 8.

Warren, P.S., and Stelck, C.R. (1956) Devonian Faunas of Western Canada; Geol. Assoc. Canada, spec. Paper 1.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M^c CONNELL
FAULT
STRUCTURE SECTION
B-B'
Waiparous
Creek
A'
NE
B'
NE
C'
NE

FIGURE 8

GEOLOGIC MAP OF THE GHOST RIVER AREA

WEST OF FIFTH MERIDIAN

ALBERTA

BY: E. L. FITZGERALD

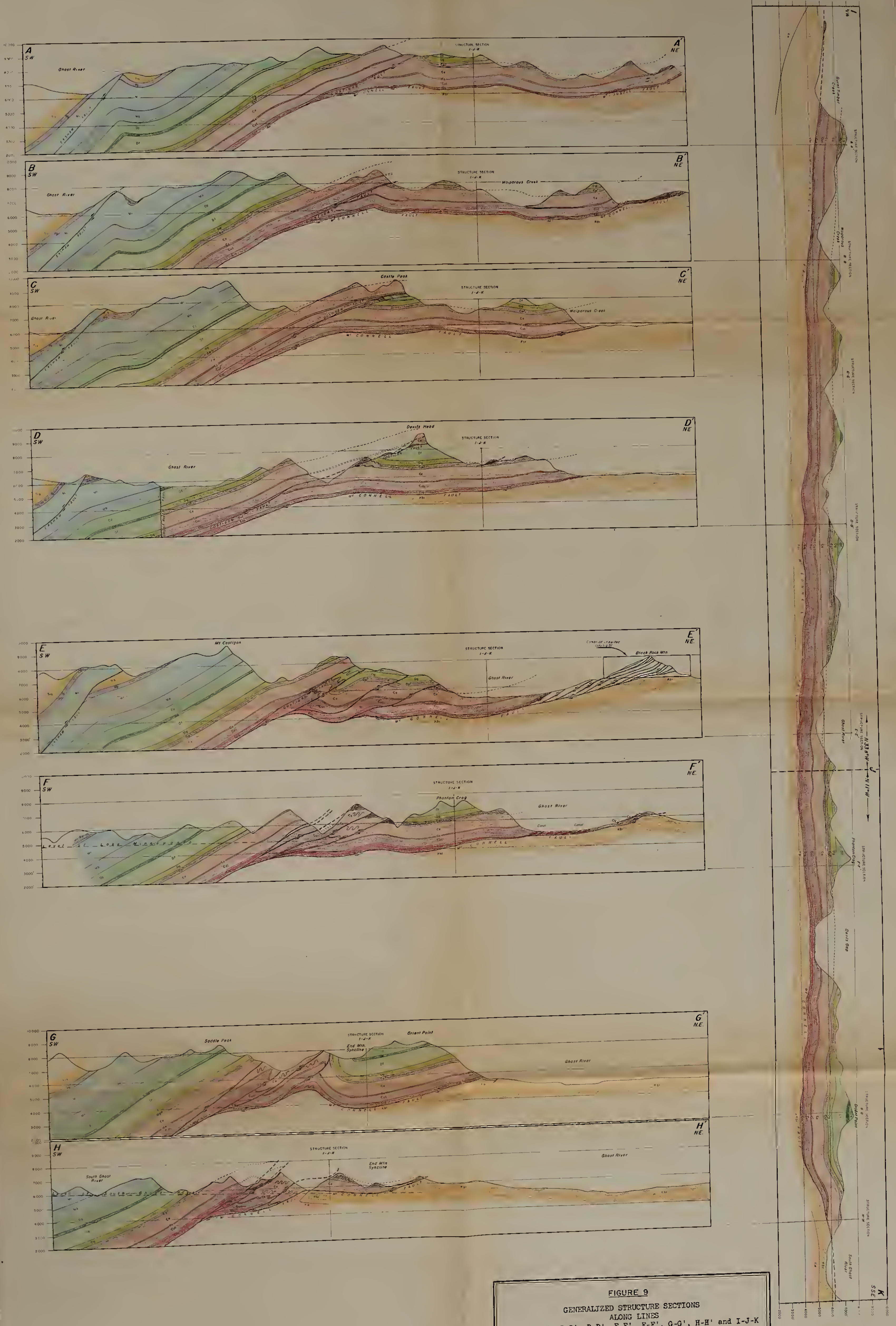

FIGURE 9

GENERALIZED STRUCTURE SECTIONS
ALONG LINES
A-A', B-B', C-C', D-D', E-E', F-F', G-G', H-H' and I-J-K
IN THE
GHOST RIVER AREA
ALBERTA

0 5000 10000

SCALE - FEET

BY: E. L. FITZGERALD